Selected Habitat Suitability Index Model Evaluations

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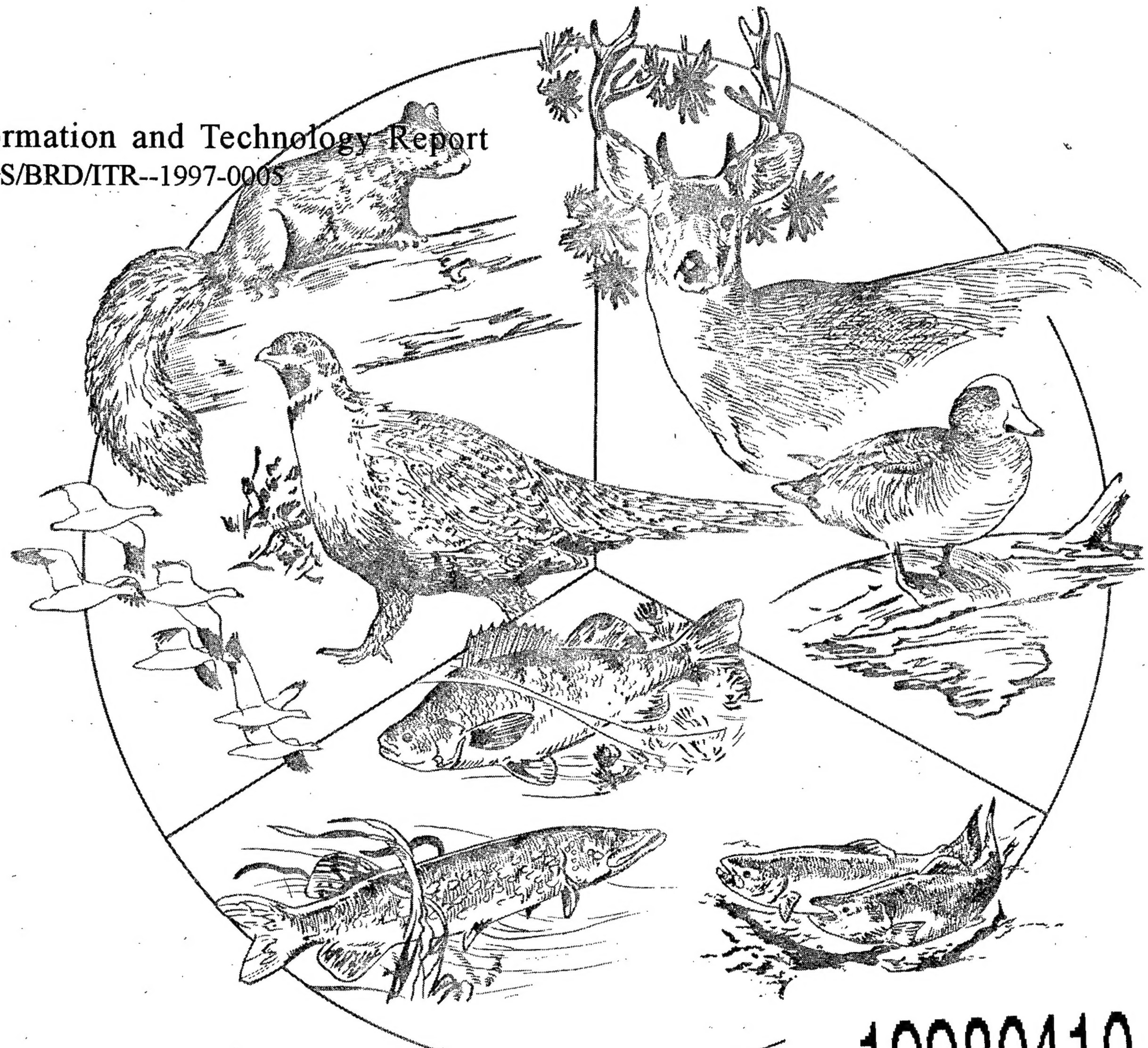

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Edited by
James W. Terrell and Jeanette Carpenter

U.S. Department of the Interior
U.S. Geological Survey
Washington, D.C. 20240

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Acronyms

breeding bird species richness	BBSR
component index	CI
diameter at breast height	dbh
dissolved oxygen	DO
Geographic Information System	GIS
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Habitat Suitability Index	HSI
habitat unit	HU
Instream Flow Incremental Methodology	IFIM
modified trout cover rating	MTCR
relative abundance index	RAI
suitability index	SI
total dissolved solids	TDS
U.S. Fish and Wildlife Service	USFWS
U.S. Geological Survey	USGS
Wildlife Habitat Assessment Guide	WHAG

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Preface

The U.S. Department of the Interior conducted or provided support for numerous Habitat Suitability Index (HSI) model evaluations between January 1, 1982, and October 1, 1995. Results of this program are dispersed among various journals, theses, dissertations, and unpublished reports. In order to simplify use of this scattered information, this publication provides referenced summaries of unpublished HSI model evaluations that were initiated by the U.S. Fish and Wildlife Service. For a limited number of species, published HSI model evaluations are summarized.

All of the authors of the individual synopses were involved in the development and testing of HSI models. Except for Janelle Corn (who is in the final stages of completing a Ph.D. program at Colorado State University), all of the authors currently work for the Biological Resources Division of the U.S. Geological Survey.

Introduction

This report summarizes unpublished and selected published evaluations of habitat suitability index (HSI) models in the HSI series (described in Appendices A, B, and C). These evaluations provide insight to behavior of individual models that should be useful to managers. Other than a few exceptions described below, studies of species habitat requirements and new habitat models published since development of the HSI series are not summarized. With the exception of Atlantic salmon (*Salmo salar*), evaluations of HSI models published in outlets other than the HSI model series are not summarized.

Individual summaries include a description of any model modifications recommended in the original publication. Very few studies considered an entire HSI model as published in the series, attempted to evaluate all of the HSI models presented in the series for a species, or defined suitability indices for habitat variables using exactly the same graphs presented in the HSI model series. Consequently, the original studies may apply to selected portions of a model rather than to the entire model.

Two levels of effort ("high" and "low") were used to select studies for inclusion in this report. The decision on what level of effort to apply was administrative, based on availability of funds and personnel. For 42 species or life stages, the wildlife guilds model, and the habitat layers model, a "low" level of effort was used. For this low level of effort, only unpublished reports initiated by the U.S. Fish and Wildlife Service and completed between September 30, 1989 and October 1, 1995 as part of a model evaluation program were summarized. Some of these unpublished reports used new habitat requirements information to develop modified HSI models.

The remaining species, species groups, species life stages, and communities included in the HSI model series, plus Atlantic salmon, were subjected to a "high" level of effort to locate HSI model evaluations (Table 1). Published and unpublished reports written between January 1, 1982 and October 1, 1995 and initiated by the U.S. Fish and Wildlife Service (USFWS) as part of a model evaluation program were summarized. Studies published prior to 1995 that were not initiated by the USFWS that compared the output of all or part of an HSI model (for the species within the scope of the high level of effort) with a response that could be assumed to be an independent measure of habitat quality or that critically examined the structure or assumptions of HSI models were summarized. Selection

Table 1. Results of effort to locate HSI model evaluations. Low level of effort indicates that the search was limited to unpublished reports developed between September 30, 1989 and October 1, 1995. High level of effort indicates that commercial abstracting services were used to search the literature to locate HSI model evaluations published between January 1, 1982 and December 31, 1994 and that unpublished and published HSI model evaluations developed as a result of the USFWS model evaluation program were summarized.

Taxon or group	Level of effort	HSI model evaluation located
Communities		
Forest birds	High	Yes
Habitat layers	Low	Yes
Riverine fishes	High	Yes
Wildlife guilds	Low	No
Wildlife species richness	High	Yes
Mammals		
Beaver	High	Yes
Black bear	High	Yes
Black-tailed prairie dog	High	No
Bobcat	High	No
Eastern cottontail	High	Yes
Fisher	High	Yes
Fox squirrel	High	Yes
Gray squirrel	High	Yes
Marten	High	Yes
Mink	High	No
Moose	High	Yes
Muskrat	Low	No
Pronghorn	High	Yes
Snowshoe hare	High	No
Southern red-backed vole (western United States)	High	No
Swamp rabbit	High	No
White-tailed deer (coastal plain)	High	Yes
Birds		
American black duck (wintering)	Low	No
American coot	High	No
American eider (breeding)	Low	No
American woodcock (wintering)	High	No

Table 1. *Continued.*

Taxon or group	Level of effort	HSI model evaluation located
Baird's sparrow	High	No
Bald eagle (breeding season)	High	No
Barred owl	High	No
Belted kingfisher	High	No
Black brant [Brant, spp. *nigricans*]	Low	No
Black-bellied whistling duck	Low	No
Black-capped chickadee	High	Yes
Black-shouldered kite [White-tailed kite]	Low	No
Blue grouse	High	No
Blue-winged teal (breeding)	High	No
Brewer's sparrow	High	No
Brown thrasher	High	No
Cactus wren	High	No
Canvasback (breeding)	High	Yes
Clapper rail	Low	No
Downy woodpecker	High	Yes
Eastern brown pelican	Low	No
Eastern meadowlark	High	No
Eastern wild turkey	High	No
Ferruginous hawk	High	No
Field sparrow	High	No
Forster's tern (breeding)	Low	Yes
Gadwall (breeding)	High	No
Gray partridge	High	No
Great blue heron	High	Yes
Great egret	Low	No
Greater prairie-chicken	High	No
Greater sandhill crane	High	Yes
Greater white-fronted goose (wintering)	Low	Yes
Hairy woodpecker	High	No
Lark bunting	High	No
Laughing gull	Low	Yes
Least tern	High	No
Lesser scaup (breeding)	High	No
Lesser scaup (wintering)	Low	No
Lesser snow goose (wintering)	Low	No
Lewis' woodpecker	High	No
Mallard (winter habitat)	Low	Yes
Marsh wren	High	No
Mottled duck	Low	No
Northern bobwhite	High	Yes

Table 1. *Continued.*

Taxon or group	Level of effort	HSI model evaluation located
Northern pintail	High	No
Northern pintail (gulf coast)	Low	No
Osprey	High	No
Pileated woodpecker	High	Yes
Pine warbler	High	Yes
Plains sharp-tailed grouse	High	Yes
Redhead (wintering)	Low	No
Red-winged blackbird	High	No
Roseate spoonbill	Low	No
Ruffed grouse	High	Yes
Spotted owl	Low	No
Veery	High	Yes
Western grebe	High	No
White ibis	Low	Yes
Williamson's sapsucker	High	Yes
Wood duck	High	No
Yellow warbler	High	Yes
Yellow-headed blackbird	High	No
Reptiles		
American alligator	Low	No
Diamondback terrapin (nesting)	Low	No
Slider turtle (Common slider)	High	No
Snapping turtle	High	No
Amphibians		
Bullfrog	High	No
Red-spotted newt	High	No
Fish		
Alewife	Low	No
American shad	High	Yes
Arctic grayling	High	Yes
Atlantic croaker (juvenile)	Low	No
Atlantic salmon	High	Yes
Bigmouth buffalo	High	No
Black bullhead	High	Yes
Black crappie	High	Yes
Blacknose dace	High	Yes
Blueback herring	Low	No
Bluegill	High	Yes

Table 1. *Continued.*

Taxon or group	Level of effort	HSI model evaluation located
Brook trout	High	Yes
Brown trout	High	Yes
Channel catfish	High	Yes
Chinook salmon	High	Yes
Chum salmon	High	Yes
Coho salmon	High	Yes
Common carp	High	Yes
Common shiner	High	Yes
Creek chub	High	Yes
Cutthroat trout	High	Yes
English sole (juvenile)	Low	No
Esox spp.	High	No
Fallfish	High	Yes
Flathead catfish	High	No
Flounders (southern and gulf coast)	Low	No
Gizzard shad	High	Yes
Green sunfish	High	Yes
Gulf menhaden	Low	No
Inland silverside	Low	No
Kokanee salmon	High	No
Lake trout	High	Yes
Largemouth bass	High	Yes
Longnose dace	High	Yes
Longnose sucker	High	No
Muskellunge	High	No
Northern pike	High	Yes
Paddlefish	High	No
Pink salmon	High	No
Rainbow trout	High	Yes
Rainbow trout (put-and-grow)	High	No
Red drum (larval and juvenile)	Low	Yes
Redbreast sunfish	High	Yes
Redear sunfish	High	No
Sauger	High	No
Shortnose sturgeon	High	No
Slough darter	High	No
Smallmouth bass	High	Yes
Smallmouth buffalo	High	No
Southern kingfish	Low	No
Spotted bass	High	Yes
Spotted seatrout	Low	Yes
Spot (juvenile)	Low	No
Striped bass (coastal)	Low	Yes
Striped bass (inland)	Low	No
Walleye	High	Yes

Table 1. *Concluded.*

Taxon or group	Level of effort	HSI model evaluation located
Warmouth	High	Yes
White bass	High	No
White crappie	High	Yes
White sucker	High	Yes
Yellow perch	High	No
Invertebrates		
American oyster (Eastern American oyster)	Low	No
Brown shrimp	Low	No
Hard clam	Low	No
Littleneck clam	Low	No
Pink shrimp	Low	No
Red king crab	Low	No
White shrimp	Low	No

of these non-USFWS studies was based on a review of abstracting service (*Agricola*, *BIOSIS*, *Dissertation Abstracts*, *Wildlife Review*, *Fisheries Review*, or Commonwealth Agricultural Bureau) publications.

Published studies that did not evaluate a model (or draft version of a model) published in the HSI series or that provided only new information on habitat requirements or descriptions of new habitat models were not summarized. Publications dealing predominantly with development or evaluation of suitability indices (or habitat suitability criteria) for use with the Instream Flow Incremental Methodology (IFIM) or evaluations of IFIM were not summarized. The results of a report (Electric Power Research Institute 1986) presenting one-page "methodology" summaries of stream versions of individual fish HSI models were not summarized for individual models. This report attempted to evaluate models as tools for making instream flow recommendations. It concluded: (1) that the individual HSI model publications did not present independent evidence that model output (HSI) is indicative of true habitat suitability, carrying capacity, or standing crop; and (2) that without such evidence there was little justification in using the models for any purpose other than focusing attention on the steps of building a model. These conclusions were based on the contents of the HSI model publications and do not consider efforts to evaluate the models with independent data or to use the models for problems other than instream flow recommendations.

Summaries of HSI model evaluations follow standard format and content guidelines. The "Summarized by" section names the author of the summary. The "Reference" section provides a full citation for the summarized report. The "Synopsis" section paraphrases the original author(s) unless there is specific language to indicate that the compiler added his or her own interpretation or critique. The "Suggested revisions" section describes model revisions (if any) suggested by the original author; if <u>none</u> appears in this section, no specific revisions were suggested. Lack of suggested revisions does not necessarily mean that the model should not or could not be revised based on the results of the study.

Implications of Results

Developed by: James W. Terrell

The single most important implication of the model evaluation program is that if an HSI model does not provide an explicit description of expected wildlife response to changes in HSI, it is difficult to determine what the model output represents. This ambiguity forces model users (and model testers) to provide their own, possibly different, definitions of what the model output means and may be an underlying cause for the lack of HSI model test results in the refereed literature reported by Brooks (1997). Although specific problem areas and solutions varied for individual model evaluations, two basic approaches to improving the efficiency of future cycles of habitat model development and testing emerge from the model evaluation program: (1) defining specifically the time, spatial scale, and range of variation of the response(s) represented by the model; and (2) using statistical metrics that incorporate the concept of limiting factors to develop models and to compare model predictions to wildlife responses. Applying these approaches will not yield "fail safe" models. Applying these approaches should, however, lead to less ambiguous models and more efficient use of existing information, which consists primarily of observational studies and correlative relationships for a variety of temporal and spatial scales. The approaches can be used with a wide variety of data, can be applied at various levels of biological organization such as species, life stages, or communities, and are compatible with more specific recommendations from individual evaluations such as incorporating a landscape context into models or using repopulation rates to test models.

Define the Response Being Modeled

Many of the models in the HSI series consist of individual Suitability Indices (SI's) that are aggregated into an HSI. The assumptions used to develop the SI's are

listed. However, the meaning of individual SI graphs would be less ambiguous if a second Y-axis were added to the graph identifying exactly what the SI represents. Examples of this approach can be found in Layher and Brunson (1992) where mean standing crop of fish (kg/ha) associated with an SI is identified on a second Y-axis for individual SI graphs and documentation is provided on how to collect data to develop graphs. When numerous studies investigating different responses to habitat variables are available in the literature, a more complex approach could be used where different measures of animal performance are represented by different SI's. For example, growth rates, numbers of fish/hectare, and survival rates were used by Terrell et al. (1995) to develop SI's for different habitat variables.

Well-defined SI's will not solve the problem of choosing the best response (as discussed by van Horne 1983 and Hobbs and Hanley 1990) for rating "habitat quality" or the problem of what to do when the temporal and spatial scales of a response (e.g., microhabitat selection by individual animals during a short time period) do not match those of the perturbation (e.g., a large scale habitat alteration that will last for years). Well-defined SI's will bring these problems into the open, where they can be recognized and the most appropriate response(s) selected (e.g., Minns et al. 1990). Clear identification of the responses represented by individual SI's should make them more useful in the type of hierarchical analyses suggested by Rabeni and Sowa (1996) who noted that effective habitat conservation requires recognizing the relative influence of each habitat variable and the spatial scale over which each operates. They recommend considering information across all spatial scales, from individual animal habitats to ecoregions, in habitat restoration, and using geographical information systems to relate complex spatiotemporal data. Identification of responses represented by individual SI's and overall HSI models will make it easier to develop meaningful aggregation functions to combine SI's in a manner that mimics biological processes. HSI models that do not use individual SI's should still be based on an explicit, well-defined response.

Use Statistical Metrics Compatible with the Concept of Limiting Factors

A habitat variable (or combination of habitat variables) can be a limiting factor without being strongly correlated with a species' (or group of species or species life stage) response. Other unmeasured factors may depress the response below the limit imposed by the habitat. Although the concept that habitat may impose a ceiling is easy to grasp, developing conclusive tests to determine if a habitat model accurately describes that ceiling is difficult. Thomson et al. (1996) describe in detail this fundamental problem in the interpretation of ecological data and note that correlation analysis may be shortsighted, or even blind to informative aspects of ecological data sets where data points are widely scattered beneath a ceiling imposed by a limiting factor.

In the past, advice for developing and testing habitat models has generally treated symptoms of the above problems rather than directly confronting them. For example, Schamberger and O'Neil (1986) emphasized testing over the entire range of habitat quality, which is a circular argument because habitat quality is represented by the model. Pajak and Neves (1987) recommended adding factors unrelated to habitat in order to develop a more accurate model. This approach can provide an accurate model, but shifts the emphasis away from modeling impacts of habitat change. Data that are scattered widely beneath an ever increasing ceiling representing improving habitat quality will exhibit heteroscedastic variance. Some authors (e.g., Gutzwiller and Anderson 1986) have emphasized transforming data and using methods such as weighted least squares regression to minimize the impact of heteroscedastic variance on estimates of central tendency. This advice is useful in designing studies to support the search for correlations but treats the pattern of variance expected to be associated with an accurate model of a limiting factor as a nuisance instead of evidence of a good model. Poor correlations and heteroscedastic data scattered beneath an upper limit can be expected with accurate models of habitat quality. HSI's defined as estimates of habitat-imposed limiting factors to responses of an individual or population should be tested with methods other than correlation analysis. Heteroscedastic variance patterns should be evaluated as evidence supporting the occurrence of limiting factors. Statistical techniques that define the upper limits and internal structure of data should be used to develop and test explicit models of habitat characteristics that act as limiting factors.

Techniques to define limiting factors statistically have been generally unknown to ecologists (Thomson et al. 1996) and were not utilized in the evaluations described in this document. However, applications defining the upper limits to data distributions using logistic slicing (Thomson et al. 1996), regression percentiles (Hubert et al. 1996), and regression quantiles (Terrell et al. 1996) are beginning to appear in the ecological literature, and Koenker and Portnoy (1996) have described advances in quantile regression that should be useful for developing models of limiting factors. In the future, these or similar methods should be used to develop and test HSI models

that predict responses of individuals or populations that will not be exceeded for a given set of habitat conditions. This approach will help derive the maximum information from data sets that describe ecological responses observed without the benefit of concurrent experimental manipulation of habitat variables. It will provide falsifiable predictions of the impact of changing the habitat.

Models that describe limiting factors or other patterns of ecological associations are only a first step to understanding ecological processes. The problem faced by managers - predicting the impact of active manipulation of habitat - is better solved by an understanding of ecological processes than reliance on the repeatability of observed patterns of association. However, unambiguous habitat models that predict the limits and expected pattern of variation of clearly-defined responses of individual animals, populations, or communities imposed by habitat variables should help insure that the first step is in the right direction.

Summaries of Habitat Suitability Index Model Evaluations for Communities

Forest Birds

Summarized by: Adrian Farmer

Reference: Van Horne, B., and J. A. Wiens. Forest bird habitat suitability models and the development of general habitat models. Region 8, U.S. Fish and Wildlife Service, *Fish and Wildlife Research 8*. 31 pp.

Synopsis: Most models published in the HSI model series are for single species and represent independent efforts where very few of the models were developed as related sets that conform to the same protocols and definitions. There may be advantages to a more structured, top-down approach wherein models for sympatric species are developed with a more general, community approach to habitat assessment.

The authors were concerned with how to develop a more general approach to habitat assessment. Specifically, their objective was to evaluate the feasibility of constructing a more general "forest bird" model by combining information contained in habitat models for 16 species. They examined other approaches to developing general, multispecies models, and they suggested an approach to model validation.

It would be difficult to develop a forest bird model based on the models in the HSI model series because the individual models differ substantially in structure and variable specifications. An alternative, and seemingly superior, approach using envirograms is described. Landscape variables should also be incorporated into habitat models. Validation efforts should focus first on testing individual model assumptions, especially those assumptions pertaining to limiting factors. Sensitivity analyses combined with field experimentation are necessary to make improvements to existing models.
Suggested revisions: None. Alternate approaches are described.

Summarized by: Adrian H. Farmer

Reference: Van Horne, B. 1990. A description and evaluation of habitat suitability index models. Transactions of the Nineteenth International Union of Game Biologists' Congress 1:303-306. Trondheim, Norway.
Synopsis: This paper is based on the same data as the previous summary but presents a slightly different emphasis. Neither this nor the previous paper is based on model tests with new data; instead both papers represent the professional opinions of the authors. Conclusions in this paper were as follows: (1) the HSI modeling effort provides a useful framework for synthesizing and making mathematically explicit our current knowledge about the relationships between a species and its habitat; (2) the HSI models should be considered working models; however, their results should not be blindly applied in management situations; (3) validation efforts should be focused on model assumptions and field experiments and simulations should be conducted; and (4) many of the models do not incorporate the landscape context, but some management applications will require that they be modified to do so.

The Habitat Layers Index Model

Summarized by: Adrian H. Farmer

Reference: Short, H. L. 1989. Test of the habitat layers index model. U.S. Fish and Wildlife Service, National Ecology Research Center, Ft. Collins, Colo. Unpublished report.
Synopsis: This test evaluated the contribution of habitat layers and areas of habitat within those layers to bird species richness and vertebrate species richness within a series of upland sites in south-central Colorado. The presence of understory, midstory, and overstory layers provided the best correlation (r = 0.93) with bird species richness, and the presence of four habitat layers provided the best correlation (r = 0.89) with vertebrate species rich-

ness. Correlations with the total combined area of habitat within understory, midstory, and overstory layers were similar ($r = 0.92$, $r = 0.85$, respectively). An HSI model based on the presence or absence of the understory, midstory, and overstory layers and the product of the total habitat area within those three layers was significantly correlated with species richness for vertebrates ($r = 0.91$) and birds ($r = 0.93$). The HSI model predicts bird species richness at least as well as foliar height diversity. An equitability component, when added to the HSI model, did not enhance the predictive capability. Because the HSI model reflects the number of habitat layers present and the total area of habitat within those layers, and seems predictive of species richness for vertebrates and birds, it should have utility in inventories and assessments of the structure of habitats on a landscape scale.
Suggested revisions: None.

Wildlife Species Richness in Shelterbelts

Summarized by: Richard L. Schroeder

Reference: Schroeder, R. L., T. T. Cable, and S. L. Haire. 1992. Wildlife species richness in shelterbelts: test of a habitat model. Wildlife Society Bulletin 20:264–273.
Synopsis: The authors tested a community-level habitat model, where the output was defined as a measure of wildlife species richness. Breeding bird species richness (BBSR) was surveyed over a 3-year period on 34 shelterbelts in south-central Kansas. Habitat and landscape measures were also obtained. Regression of BBSR on HSI showed a highly significant relationship ($r^2 = 0.822$, $P < 0.001$). Number of shelterbelt rows was difficult to measure in older shelterbelts; measures of tree canopy closure were difficult to measure in very narrow belts. Cavity-nesting bird species composed a large part (24%) of overall BBSR, and species richness of cavity-nesting birds was significantly correlated with snag density. The model test confirmed the importance of shelterbelt size in predicting species richness. Shelterbelts containing interior or area-sensitive birds were larger, taller, wider, and contained higher snag density and foliage height diversity than shelterbelts lacking such bird species.
Suggested revisions: New variables and a revised HSI model were presented in the report. These revisions reduced the number of habitat variables from five to three and included a revised variable for shelterbelt size. Original model variables for tree or shrub canopy closure, number of shelterbelt rows, number of woody plant species, and shelterbelt configuration were eliminated. The variable for height of the tallest row was retained, and new variables were included to measure foliage height diversity and snag density. Regression of BBSR on the revised HSI indicated an improved fit ($r^2 = 0.893$, $P < 0.001$).

Riverine Habitat Suitability Index Models

Summarized by: James W. Terrell

Reference: Bain, M. B., and C. L. Robinson. 1988. Structure, performance, and assumptions of riverine habitat suitability index models. Alabama Cooperative Fish and Wildlife Research Unit, Auburn. Aquatic Resources Research Series 88–3. 20 pp.
Synopsis: The authors examined HSI model publications for 30 freshwater riverine fish species and identified common components, variables, computational rules, and equations. A composite model was developed to capture typical characteristics and assumptions of riverine HSI models and to analyze model behavior. The composite model had 11 variables and 3 components (water quality, reproduction, and food and cover). Sensitivity analysis and computer simulations of hypothetical impacts (such as stream channelization) were used to analyze model behavior. The generalized model closely paralleled many of the riverine HSI models reviewed.

The most significant structural characteristics of the reviewed (and composite) models were use of water temperature, dissolved oxygen (DO), and cover variables; ambiguity in the definition of cover and why it is important; and the linking of food and cover into one component.

Behavior of limiting factor (select the lowest suitability index [SI] as the HSI) models was obvious and did not require additional sensitivity analysis. Behavior of models based on various aggregation techniques such as means, or means combined with a limiting factor approach if a variable had an SI of less than 0.4, was more complex. In general, the outputs of models that were not based on limiting factors were very similar regardless of weighting factors. Weighting factors may not have had as much impact on the model outputs as the model author(s) intended. The number of variables per component had an effect on model output, and use of threshold values abruptly changed model structure and performance.
Suggested revisions: Major suggestions for improving riverine models include: (1) develop better documentation of how threshold values were selected for changing from variable aggregation based on means to limiting factor models, (2) test assumed linkages of food- and cover-related variables, and (3) develop better spatial and temporal criteria for rating temperature and oxygen regimes.

Reference: Bain, M. B., and C. L. Robinson. 1988. Strategies for testing riverine habitat suitability index models. Alabama Cooperative Fish and Wildlife Research Unit, Auburn. Contribution 2 of the Aquatic Habitat Modeling Project. 13 pp.
Synopsis: The authors describe: (1) several approaches to testing HSI models, (2) how some of the approaches can be applied to assumption testing, and (3) a strategy for completing some assumption tests. Most HSI model tests that attempt to correlate population density (numbers or biomass per unit area) with HSI's are unreliable and unable to provide strong evidence for or against model validity because of the impact of unmodeled factors on short-term population levels. Measures of population productivity are suggested for testing larval components of riverine fish HSI models. The authors argue that few tests of models are based on true indicators of carrying capacity. Three potential approaches for testing riverine stream fish HSI models are: (1) population manipulation experiments to measure repopulation rates, (2) fish distribution studies within a single stream based on the Fretwell-Lucas model of habitat selection, and (3) long-term monitoring of population density.

Model variables related to temperature, cover, and food supply should be tested. Variables related to these components are common to many riverine fish HSI models, and improvements in variable ratings could be applicable to several models.

Reference: Bain, M. B., and B. M. Wood. 1991. Field tests of habitat suitability index models for warmwater stream fish. Unpublished report, Alabama Cooperative Fish and Wildlife Research Unit, Auburn.
Synopsis: The authors tested the generalized riverine fish habitat model described in the first synopsis of this section and the riverine version of seven HSI models for individual species (bluegill, green sunfish, redbreast sunfish, warmouth, spotted bass, largemouth bass, and channel catfish). A rigorous approach was used to test if relative population density under an ideal free distribution was correlated with HSI.

Three field experiments were conducted using three or four study areas in each of three widely separated stream basins in central Alabama. Data on physical and chemical habitat attributes were obtained from field measurements, published data, and a water quality data base (STORET). Field measurements of habitat were made once at each study area during late summer or early fall base flow discharge. A series of 200 physical habitat measurements were made at each study reach by sampling at five points on each of 40 transects. Data for each habitat variable were computed at two levels of spatial resolution: study reach (entire length of the habitat characterization) and the fish sampling site (segment where fish were sampled). Fish populations were estimated by removal sampling and the maximum likelihood estimator.

Stream habitat suitability was estimated with the riverine versions of published HSI models. Fish abundance was reported as density of fish (number/100 m^2) and biomass (g/100 m^2). Pearson product-moment correlation coefficients were calculated for HSI and fish density. Correlations were reported by species and fish sampling period for two levels of spatial resolution (reach, site), two levels of models (full, reduced), and two estimates of fish abundance (numbers, biomass).

Model data requirements were met with field measurements and data bases of environmental quality agencies. Hence, the HSI models were practical for rapid, low-cost applications.

Results from three independent field experiments produced contradictory evidence relative to the accuracy of the HSI models. Model predictions were correlated with measures of fish abundance only where there were major differences among study areas within a stream basin. The mixed results indicate that riverine stream fish HSI models can discriminate among sites differing in habitat suitability only when there are very large differences in habitat characteristics.

There was strong similarity among individual species and generalized model HSI scores and habitat-HSI correlations. This pattern indicates that most variables are unimportant because a few physical habitat variables determine the results. The most concise and robust single model would be the reduced, generalized model.
Suggested revisions: Water quality and temperature variables may be eliminated if water quality is not a problem. It may be possible to use a general model for groups of species.

Reference: Miller, A. C., K. J. Kilgore, B. S. Payne, and J. Franklin. 1987. Community habitat suitability models for warmwater fishes. Miscellaneous paper EL-87-14. Environmental Laboratory, Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss.
Synopsis: There are two basic problems in published HSI models for warmwater riverine fish. First, data requirements of most models are difficult to meet because they have too many variables, many of which are time consuming to measure. Second, models for closely related species that use the same types of habitats often provide different HSI scores when there are no ecological reasons for these discrepancies. Even though no comparisons of model outputs to independent measures of habitat quality, such as abundance or growth, were made, the

authors concluded that because HSI models for cogeneric species (e.g, *Leopomis* spp.) provided different habitat ratings, those models must be incorrect.

Community models were developed to replace the species models and solve the two basic problems identified by the authors. Five variables consistently used in the species models (percent cover, water depth, water velocity, pH, and dissolved oxygen) were used for community models. For each genus of fish, published SI curves for each of the five variables were averaged to develop a composite SI curve for the genus. The arithmetic mean of the five individual SI's is the "community" HSI for the genus. These community models are much less complex (they only contain five variables) than single-species models, are applicable to general planning studies, and could be modified if site-specific data were available.
Suggested revisions: None. Community models are proposed as effective alternatives to single-species models.

Summaries of Habitat Suitability Index Model Evaluations for Mammals

Beaver (Castor canadensis)

Summarized by: Bruce W. Baker

Reference: McComb, W. C., J. R. Sedell, and T. D. Buchholz. 1990. Dam-site selection by beavers in an eastern Oregon basin. Great Basin Naturalist 50:273–281.
Synopsis: The authors evaluated the original beaver HSI model and modified it for site-specific conditions in eastern Oregon. All sites were in the shrub-steppe ecosystem, whereas the original model was based on data from forested ecosystems. Because all sites were in the same drainage and had the same SI value for water level fluctuation (SI = 0.05), the authors eliminated this variable in the modified model. They also evaluated three other habitat models for beaver, including the Missouri HSI model. Their study compared HSI values at 14 occupied and 41 unoccupied dam sites, thereby using selection of a damsite by beaver as the performance measure. Terrestrial habitat variables were measured in two 40-m-diameter plots at each site. They also measured other aspects of dams and their locations, such as height, diameter of stems cut by beaver, and percentage of available stems cut by beaver. They used a *t*-test to compare HSI values at occupied and unoccupied sites.

Average HSI values of occupied and unoccupied sites differed significantly for the original and modified models. Based on the original model, average HSI was 0.39 at occupied sites and 0.20 at unoccupied sites. Eliminating water level fluctuation from the model yielded an average HSI of 0.79 at occupied sites and 0.29 at unoccupied sites.
Suggested revisions: Because water levels did not vary among sites, model performance improved by eliminating the water level fluctuation variable. However, the variable should not be eliminated from the model when comparing areas with different water regimes. The stream gradient variable could be improved by using relative (cross-sectional stream area at a given gradient) instead of absolute gradients. Sampling a wide range of absolute gradients resulted in a Gaussian distribution with similar means for occupied and unoccupied reaches even though the range of values for width and depth was narrower at occupied sites.

A logical decision tree, based on stream gradient and hardwood cover, is suggested as an alternative to the HSI model. Bank slope might be a locally important variable but should not be included in models covering all possible beaver habitat.

Reference: Fox, L. B. 1991. Field test of beaver HSI model: An evaluation of stream sites in eastern Kansas where recent habitat modifications had occurred during road and bridge construction. Unpublished report, Cooperative Agreement No. 14-16-0009-88-936 (Task Order 1) between U.S. Fish and Wildlife Service, Fort Collins, Colorado, and Kansas Department of Wildlife and Parks, Emporia.
Synopsis: Fox evaluated the beaver HSI model at 25 recently finished road and bridge construction (treatment) sites and 25 control sites in Kansas. Winter food availability and beaver response were measured in 6-ha areas using belt and line transects. The performance measure was biomass of food cut by beaver at each site. HSI values were computed for subareas of each cover type based on their visual appearance. Paired *t*-tests were used to compare model variables at treatment and control sites. Tree canopy cover averaged 84.9% at control sites and 58.9% at treatment sites. Control sites had more water surface area. No other variables were statistically different. There were also no differences in HSI values between treatment and control areas or between areas with and without beaver activity. Kilograms of cuttings per hectare and individual model variable SI's for each study site were not correlated, indicating the model did not accurately predict habitat quality for beaver. The variable "average water level fluctuation" was the dominant influence on HSI, making the model insensitive to changes in other variables.
Suggested revisions: The model incorrectly treats all deciduous trees (other than four species) as equal in value and uses circuitous methods to estimate food availability. An alternative based on variables that measure volume of

potential winter food, as well as size class, distance from water, and preference by beaver, should be developed. Average water fluctuation should be quantified differently or dropped from the model, at least for Kansas. Soil texture and height of the streambank above normal water levels may be important variables for river systems where beaver build bank dens instead of lodges. Transects perpendicular to the stream should be used to estimate riparian zone width.

Reference: Baker, B. W., D. L. Hawksworth, and J. G. Graham. 1992. Wildlife habitat response to riparian restoration on the Douglas Creek watershed. Pages 62–80 *in* Proceedings of the Colorado Riparian Association, November 4–6, Steamboat Springs.

Synopsis: The authors reported preliminary results of testing the model assumption that canopy cover and height of hydrophytic vegetation are good predictors of winter food availability for beaver. The study was conducted in the shrub-steppe ecosystem of western Colorado, at a site where beaver populations varied greatly and coyote willow (*Salix exigua*) was the only winter food available.

The objective was to compare actual food availability to the presumably more crude estimates of canopy cover and height, as defined by the model. The authors estimated actual food values on 0.5- x 1.0-m plots by multiplying stem density by diameter class times the oven-dried biomass of beaver food for the diameter class. Beaver food biomass estimates were predicted from sample means. Estimates were based on a sample of 160 willow stems collected from the site. Beaver food consisted of bark and small twigs that were removed by clipping and peeling and then weighed. Data analysis had not been completed.

Suggested revisions: None.

Reference: Robel, R. J., L. B. Fox, and K. E. Kemp. 1993. Relationship between habitat suitability index values and ground counts of beaver colonies in Kansas. Wildlife Society Bulletin 21:415–421.

Synopsis: The authors evaluated the model at 21 25-km sections of riverine habitat in northern and eastern Kansas. Cottonwood (*Populus* spp.) and willow (*Salix* spp.) dominated the woody vegetation. The number of beaver colonies per kilometer of stream, estimated by ground census procedures, was the performance measure used to test the model. Habitat variables were estimated on 1-km segments within each of the 21 riverine sections. The line intercept method was used to estimate canopy cover of trees and shrubs.

HSI's based on the unmodified model ranged from zero on two sites to 0.67 on 12 of the remaining 19 sites. The 12 values of 0.67 resulted from a constraint in the model that requires truncating woody vegetation values to 1.0 if products exceed 1.0. Correlation of HSI values with colony density indicated that only 17% of the variation in counts was explained by the original model. Removing the truncating constraint improved model performance, resulting in two-thirds of the variation being explained by the modified model. Examination of plots of individual habitat variables against beaver colony abundance led to a change in the shrub crown cover suitability index to give maximum value at 15% instead of 60% canopy cover. Regression models to predict colony abundance from woody habitat variables were not significant at the 0.05 alpha level. The variables, as they are currently scaled in the model, are not well suited to predicting the number of beaver colonies per 25 km of riverine habitat in Kansas; either the variables in the model were not important in the Great Plains or the SI curves were not correctly scaled. Authors attributed this problem to the model being based on beaver requirements in northern or mountainous terrain.

Suggested revisions: The constraint truncating woody vegetation values to a maximum of 1.0 should be modified. Addition of several new variables, including water quality, stream or river substrate, proximity to rowcrop agriculture, and availability of livestock feeding stations, may be helpful.

Black Bear (Ursus americanus)

Summarized by: Janelle Corn

Reference: Hirsch, J. G. 1989. Black bear habitat utilization and habitat model validation in Michigan. Michigan Department of Natural Resources, Wildlife Division Report No. 3124, Ann Arbor.

Synopsis: Hirsch studied black bear habitat use and tested the black bear HSI model on Drummond Island in Lake Huron, near Michigan's Upper Peninsula. Radio-collared bears were located during the active seasons (spring through fall) in 1988, and habitat types were classified using aerial photographs and Michigan Department of Natural Resources agency classification data. HSI variables were measured in a random sample of stands of each habitat type using sampling procedures recommended in the HSI model. Seasonal habitat use by individual bears was compared with available habitat in their home ranges using chi-square tests. The HSI's of individual home ranges were compared with home range size, litter size, cub weight gains, and average daily movements using Spearman rank correlation tests.

Black bear home range vegetation types did not differ from available vegetation, but use of vegetation types within home ranges varied from those available. HSI scores were not correlated with any of the response vari-

ables identified as potential indicators of habitat quality. However, sample sizes were small ($n = 6$ to 15), and HSI's were low, not representing the range of values covered by the model. Because isolation of the island population may prevent bears from responding as they would on the mainland, Drummond Island may not be a good location for a black bear model test, even though it is within the geographic range of the model. Additionally, variation in bear diets across the area of model applicability may require modifications to the model as more information becomes available.

Suggested revisions: Use an earlier draft of the model to calculate SI's for percent of area in summer food-producing vegetation types and human intolerance. Additional research is needed to establish suitability indices for spring food abundance and relations of basal area to hard mast production. An alternative formula for calculating the black bear HSI that gives summer and fall food requisites more weight in the final HSI score was presented.

Reference: Zimmerman, J. W. 1992. A habitat suitability index model for black bears in the southern Appalachian region evaluated with location error. Ph.D. dissertation, North Carolina State University, Raleigh. 167 pp.

Synopsis: Zimmerman developed and tested a habitat suitability index model for black bears in the southern Appalachian Mountains. Variables for mast production, tree size, and stand age were similar to those in the published HSI model. The test was conducted in a 220-km^2 area in western North Carolina using systematic vegetation sampling at 2-km intervals and radiotelemetry locations of 19 black bears for 2 years. Zimmerman evaluated whether bear habitat use was nonrandom, whether habitat use by bears increased with greater HSI values, and whether the number of bears using habitats increased with greater HSI values. Frequency distributions of use and availability of habitats in 10 HSI classes were compared with chi-square tests. Trends in habitat use were compared with trends in HSI using correlation tests.

Intensity of use of habitats by bears increased with increasing HSI, and habitat preference was positively correlated with HSI. While the bear population as a whole used habitats preferentially and preferred those habitats with greater HSI's, individual bears for the most part did not use habitats within their home ranges preferentially. Habitat sampling may have been conducted on too large a scale to detect selection at the individual level. Overlap of use of habitats by bears was positively correlated with HSI values. Individual components of the HSI model were tested against habitat preference. The life requisite value for escape cover did not correlate well with habitat use by bears.

Suggested revisions: Zimmerman recommended sampling vegetation at a finer scale than he used for application of his HSI model. This recommendation probably applies to the published HSI model as well. He suggested omitting the escape cover life requisite value because other variables seem to represent this habitat requirement. Although Zimmerman omitted a variable for interspersion of cover in a second-generation model, he does not advocate its omission for other applications until the second generation model is tested.

Eastern Cottontail (Sylvilagus floridanus)

Summarized by: Tom Stanley

Reference: Wattrus, J. M. 1993. Habitat evaluation procedures at Ray Roberts Lake: An analysis of the relationship with ecological indicators and a study of observer and temporal variability. M.S. thesis, University of North Texas, Denton. 98 pp.

Synopsis: Data were collected for the eastern cottontail at Ray Roberts Lake in 1987 (predevelopment) and 1990 (postdevelopment). Three hypotheses were tested: (1) HSI values are not affected by using multiple observers (observer variability), (2) there are no differences in predevelopment and postdevelopment HSI values, and (3) there is no correlation between habitat units (HU's) and cottontail density.

Wattrus found significant observer variability for percent shrub crown cover measurements. She attributed this to lack of experience on the part of two observers. For all other cottontail model variables there were no significant differences among observers. There were no significant differences between predevelopment and postdevelopment HSI values. However, the power of this study to detect differences was low. Owing to the lack of suitable population estimates, tests for correlations between HU's and cottontail density could not be made.

Suggested revisions: Wattrus suggested that observer variability could be reduced using models with fewer subjective variables.

Fisher (Martes pennanti)

Summarized by: Janelle Corn

Reference: Thomasma, L. E., T. D. Drummer, and R. O. Peterson. 1991. Testing the habitat suitability index model for the fisher. Wildlife Society Bulletin 19:291–297.

Synopsis: The authors evaluated the fisher HSI model in the Upper Peninsula of Michigan to determine whether it accurately represents habitat suitability for the species. They measured habitat characteristics where transects intersected fisher tracks and at systematically sampled

locations along transects. Performance of model variables was evaluated with step-wise regression and graphical comparison of SI curves with response curves from their field study.

The authors reported good agreement between the HSI model and habitat use by fishers. Habitat preference increased with increasing HSI. The only habitat type that was not accurately evaluated by the model was pine plantations, which were not used by fishers but received average HSI ratings. Stepwise regression indicated that only two (diameter at breast height of overstory trees and percent of overstory tree canopy composed of deciduous trees) of the four variables in the model were significant. However, the stepwise technique has been criticized for varying results depending on the order in which variables are added to the regression. Tree canopy diversity did not permit discrimination between used and available plots. The model should not be applied to pine plantations, nor should results of this test be taken as evidence that the model will work in habitats other than those found in the Upper Peninsula of Michigan. Although the authors found redundancy in some model variables, they did not recommend omitting any variables, either because the variables describe habitat components known to be important to fishers (e.g., percent tree canopy closure) or because they could not fully test the variable (tree canopy diversity) with study area data.
Suggested revisions: None.

Fox Squirrel (Sciurus niger)

Summarized by: Janelle Corn

Reference: Wattrus, J. M. 1993. Habitat evaluation procedures at Ray Roberts Lake: An analysis of the relationship with ecological indicators and a study of observer and temporal variability. M.S. thesis, University of North Texas, Denton. 98 pp.
Synopsis: Wattrus examined changes in habitat around Ray Roberts Lake in Denton County, near Dallas, Texas, before (1987) and after (1990) impoundment. She tested some HSI models and examined observer error and interyear variation in the outputs of others. The fox squirrel HSI model was used to evaluate oak-dominated upland forests. Although too few squirrels were counted to test the model, it was possible to compare model outputs between years. Suitability indices were compared between years using Mann-Whitney U -tests.

Significant changes in model outputs (habitat ratings) from the fox squirrel HSI model occurred in percent canopy cover of hard mast-producing trees (V1) and average diameter at breast height (dbh) of overstory trees (V3), even though there were no changes in the upland forest habitat. The interyear differences were attributed to sampling and user error. Canopy cover declined from 1987 to 1990 such that the SI declined from 0.87 to 0.11. The decline was attributed to timing of sampling, which occurred in summer 1987 and fall 1990. Average dbh declined from 1987 to 1990 as well, causing a decline in the SI from 0.85 to 0.04. In this case, Wattrus thought that the x-axis of the SI curve for dbh was read improperly. The x-axis scale is labeled in centimeters and inches; in 1987, data may have been recorded in centimeters, but values for this SI may have been interpreted by examining the x-axis along the inch scale.
Suggested revisions: Season of sampling can have important effects on habitat evaluations and applications of HSI models. Sampling should occur as recommended in the models and should be consistent between years when areas are sampled repeatedly. The x-axes of some SI curves in this model, and in many other HSI models, are reported in inches and centimeters; users should be careful to interpret scales properly.

Reference: Seng, P. T. 1991. Evaluation of techniques for determining tree squirrel abundance and habitat suitability in central Missouri. M.S. thesis, University of Missouri, Columbia. 117 pp.
Synopsis: Seng compared two habitat assessment techniques to one another and to estimates of population densities of fox and gray squirrels in six 49-ha oak-hickory study areas in central Missouri in winter. Habitat assessment techniques applied were the HSI and a wildlife habitat assessment guide (WHAG) used in Missouri. The WHAG is like the HSI in that a few variables describing structural characteristics of vegetation are used to rate habitats on a scale from 0 to 1. The fox squirrel WHAG contains 11 habitat variables, including all of those found in the HSI model except understory shrub canopy cover. Additional WHAG variables represent habitat interspersion and estimates of grazing pressure. Population estimates were Lincoln-Peterson indices calculated from winter mark-recapture live trapping. Spearman's ranked correlation analysis was used for statistical comparisons.

Seng found no correlation between HSI and WHAG estimates of habitat suitability. The HSI model rated habitats as average (0.5), while the WHAG rated habitats in the good to excellent range (0.75 to 1.0). Neither rating fit the population estimates for fox squirrels; Seng found no correlation between HSI or WHAG estimates and Lincoln-Peterson estimates of population size. Several possible reasons were given for the lack of agreement between habitat models and population estimates. The most likely explanation is that the study included areas with a range of squirrel densities but not a range of habitat types.

The HSI model was consistently successful in predicting which squirrel species (fox or gray) would be most abundant in each study area, based on the Lincoln-

Peterson estimates. This discriminating power was attributed to the inclusion of the variable for percent canopy cover of understory shrubs, which is modeled to decline with increasing habitat suitability for fox squirrels.
Suggested revisions: Seng recommended using a range of habitat types to test habitat models. He concluded that HSI models are not designed to evaluate subtle differences between habitats within a habitat type with varying squirrel densities. He suggested that further research be conducted to examine the importance of understory shrub cover in the fox squirrel habitat model.

Reference: Brenner, F. J., and T. Johnson, III. 1989. Use of habitat suitability index (HSI) models to evaluate fox and gray squirrel habitat in western Pennsylvania. Journal of the Pennsylvania Academy of Science 63:77–80.
Synopsis: Squirrel habitat suitability was evaluated in four woodlots in western Pennsylvania using fox squirrel and gray squirrel HSI models. Two woodlots contained fox and gray squirrels and two contained only gray squirrels. HSI values for woodlots with and without fox squirrels were compared. Data are presented for raw values for the variables used in the HSI model in each woodlot and for calculated HSI's for winter food and cover/reproduction components of the model for each woodlot.

HSI's did not differ significantly between woodlots with and without fox squirrels. All woodlots rated acceptable for fox squirrel, although none rated as optimal. Percent canopy closure was greater than 60% on all woodlots, and shrub cover exceeded 30% in three of four woodlots. The only consistent differences between woodlots with and without fox squirrels were distance to agricultural land (greater in unoccupied than occupied woodlots) and percent shrub crown area (greater in occupied woodlots). The authors did not report numbers of fox squirrels, only the percentage of the population composed of fox and gray squirrels. Differences in proportions of two species in different habitats cannot be evaluated by HSI models.
Suggested revisions: None. However, the results of this paper indicate that the model defines percent shrub crown cover and percent tree canopy closure too restrictively for woodlots in western Pennsylvania. Proximity to agricultural fields may be more important to fox squirrels than is reflected in the model.

Gray Squirrel (Sciurus carolinensis)

Summarized by: Janelle Corn

Reference: Seng, P. T. 1991. Evaluation of techniques for determining tree squirrel abundance and habitat suitability in central Missouri. M.S. thesis, University of Missouri, Columbia. 117 pp.
Synopsis: Techniques for this study are described in the synopsis for the same reference under fox squirrel.

Seng found no correlation between HSI and WHAG estimates of habitat suitability. The HSI model rated habitats as average (0.5), while the WHAG rated habitats in the good to excellent range (0.75 to 1.0). Neither rating fit the population estimates for gray squirrels; Seng found no correlation between HSI or WHAG estimates and Lincoln-Peterson estimates of population size. Several possible reasons were given for the lack of agreement between habitat models and population estimates. The most likely explanation is that the study included areas with a range of squirrel densities but not a range of habitat types, so the test was probably too limited in scope for the stated objective. Seng recommended using a range of habitat types to test habitat models. He concluded that HSI models are not designed to evaluate subtle differences between areas within a habitat type with varying squirrel densities.
Suggested revisions: None.

Reference: Brand, G. J., S. R. Shifley, and L. F. Ohman. 1986. Linking wildlife and vegetation models to forecast the effects of management. Pages 383–397 *in* J. Verner, M. L. Morrison, and C. J. Ralph, editors. Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison.
Synopsis: The authors evaluated the feasibility of linking the gray squirrel HSI model with a tree growth simulation model to evaluate future economic and wildlife habitat impacts of several alternative forest management plans. A gray squirrel HSI model from FWS/OBS-82/10.19 was used in the test. This model differs slightly from the revised model [Biological Report 82(10.135)]. It uses a single variable to represent mast-producing tree species dominance and size when calculating an SI for winter food, rather than the two variables used in the revised model. The SI for cover/reproduction also includes a variable for shrub crown cover omitted from the revised model. The tree growth model predicted future density, dbh, and species composition of forest stands, and estimated economic return from harvests, using baseline information from Forest Service timber inventories. Estimates of species composition and dbh from this model were used directly to estimate SI values for most of the variables in the HSI model. Canopy cover was estimated indirectly from dbh using species-specific regression equations obtained from the literature.

The linked model predicted different outcomes for forest economics and habitat suitability under different management scenarios. The SI most sensitive to different management alternatives was shrub canopy cover,

the HSI model variable least amenable to prediction by the tree growth model. The tree growth model performed well, and the linked models were useful for evaluating impacts of forest management on gray squirrel habitat. The gray squirrel HSI model was not compared with responses of gray squirrels to habitat alterations but appeared to be reasonable to the authors.

Suggested revisions: Use tree growth models to predict changes in HSI model variables and subsequent impacts of forest management on wildlife habitat. The shrub crown cover variable (which is not in the revised model) was poorly suited for this type of prediction. However, the remaining variables (which are in the revised model) were readily estimated, directly or indirectly, from tree growth model simulation runs.

Reference: Tennessee Valley Authority. 1993. Draft environmental impact statement on the natural resource management plan at Land Between the Lakes. TVA/LM-93/9. Golden Pond, Kentucky. 247 pp.

Synopsis: Habitat Suitability Index (HSI) models were used to estimate the effects of alternative management plans on wildlife on the Land Between the Lakes National Recreation Area. The gray squirrel was one of six wildlife species considered. The gray squirrel HSI model was modified to better fit the value to squirrels of large sawtimber stands with many preferred red oak trees (in contrast to old-growth forests with no red oak trees) by making the variable for percent canopy cover of trees (SIV3) equal to 1.0 for canopy cover greater than 40%. Thirteen vegetative cover classes were defined and habitat variables were measured on transects and plots in all cover classes. HSI's were calculated as weighted sums over all cover classes in the area sampled. Habitat units (HU's) were calculated by multiplying HSI's by the size of the recreation area. HSI's were calculated for forest stand conditions using a vegetation simulation model, which adjusted amounts of each cover type due to succession and various management actions. Vegetation changes and HSI's were estimated at 10-year intervals for 100 years under each of five alternative management plans. Effects of alternatives on wildlife were assessed by comparing levels and changes in HU's over time.

One of the management objectives evaluated was to provide wildlife viewing and hunting opportunities. The HSI application was useful because it quantified projected differences in habitat quality among management plans. The models met application objectives in that they were biologically accurate, practical to apply, and could be linked to the vegetation simulation model. HSI models were easy to use and provided results that were objective, easy to understand, and comparable to other studies that used HSI's. The authors thought HSI models were useful for evaluating vegetation management actions because they assess habitat in terms of physical and vegetative variables that are altered with such management actions.

Suggested revisions: The users modified HSI model variables to fit unique conditions resulting from specific logging practices; these changes would not be required in other forests.

Reference: Allen, A. W., and J. G. Corn. 1990. Relationships between live tree diameter and cavity abundance in a Missouri oak-hickory forest. Northern Journal of Applied Forestry 7:179–183.

Synopsis: Allen and Corn tested the assumption that cavity abundance increases with increasing tree age or size in oak-hickory forests in Missouri. They identified tree species, measured dbh's, and counted cavities in 0.1-ha plots on 65 forest stands varying in age from 10 to 138 years. Cavities were identified from the ground with the aid of binoculars.

Average dbh of cavity trees was larger than the overall average dbh of all trees, and the percentage of trees with cavities increased with increasing dbh. However, plot average dbh explained little (5% to 35%) of the variance in cavity counts among plots. Plot characteristics such as stand age, site index, and basal area did not improve the relation between average dbh and cavity counts. The authors concluded that plot history, which is unmeasured by stand data collected by U.S. Forest Service surveys, has strong influences on cavity formation.

Regression models developed to predict the number of cavity trees based on species composition and tree size classes were tested with a second data set. Six of 10 models predicted cavity tree occurrence not significantly different ($P > 0.05$) from observed occurrence. Test data were then combined with the original data to develop refined versions of these six models. The resulting regression models predict cavity occurrence, not quality. The percentage of cavities actually used by gray squirrels or other cavity-dependent species is unknown.

Suggested revisions: Use the predictive models to estimate cavity abundance more accurately than simply using mean dbh of overstory trees (SIV5), as suggested in the HSI model. Because susceptibility to cavity formation may vary by species, use the regression models only for the species of trees used in model development.

Reference: Brenner, F. J., and T. Johnson, III. 1989. Use of habitat suitability index (HSI) models to evaluate fox and gray squirrel habitat in Western Pennsylvania. Journal of the Pennsylvania Academy of Science 63:77–80.

Synopsis: Methods are described in the synopsis for this same paper under fox squirrel. The authors did not report numbers of squirrels, only the percentage of the

population composed of fox or gray squirrels. They did not test gray squirrel habitat use versus woodlot HSI because gray squirrels were found in all four woodlots. HSI's did not differ significantly for gray and fox squirrels. All woodlots rated acceptable for gray squirrel, although none rated as optimal.
Suggested revisions: None.

Marten (Martes americana)

Summarized by: Janelle Corn

Reference: Laymon, S. A., and R. H. Barrett. 1986. Developing and testing habitat-capability models: Pitfalls and recommendations. Pages 87–91 *in* J. Verner, M. L. Morrison, and C. J. Ralph, editors. Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison.
Synopsis: The authors tested three HSI models in northern California. The marten HSI model was tested on eight sites of about 800 ha each in northeastern California. Model habitat variables were measured from 1:24,000 vegetation-type maps or aerial photographs, or (in the case of percent cover of downfall) by visual estimation along transects. Marten habitat use was measured by visitation rates to baited smoked-aluminum track plates during winter and spring 1982. The response was tested against HSI's with the Kruskall-Wallis trend test for nonparametric data.

Marten visitation rates increased with increasing HSI's, but the trend was not significant ($P = 0.06$). The authors stated that a larger sample size may have resulted in a statistically significant finding. They noted that the habitat variable presumed to be most closely correlated with carrying capacity of marten--dead and downed wood cover--cannot be estimated from existing maps, photographs, or forest inventory data. Information on model variables that is unavailable from Forest Service data bases should be collected during forest stand inventories.

The authors concluded that the model performed poorly and should not be used in management applications. Their conclusion was based on the significance level ($P = 0.06$) of the comparison between HSI's and marten visitation rates. Model users willing to accept this significance level could find the model useful in management applications.
Suggested revisions: None.

Reference: Schultz, T. T., and L. A. Joyce. 1992. A spatial application of a marten habitat model. Wildlife Society Bulletin 20:74–83.
Synopsis: The authors tested the effects of sample unit (or grain) size and spatial distribution of habitats on habitat quality ratings using a Geographic Information System (GIS) and a simple marten habitat model developed by the Colorado Division of Wildlife and the U.S. Forest Service. This model uses forest type and stand age classes to rate habitats at four levels (unsuitable, optimal, one-half optimal, and one-fifth optimal) for food and cover.

Marten habitat quality ratings were affected by grain size. In good quality habitat, the smallest spatial scales of application (about 1% of a home range size of 212 ha) rated habitats similarly. For grain sizes greater than 1%, more habitat is rated unsuitable because small rare patches of good habitat are no longer measured. In poor quality habitats, spatial scale did not affect the ratings of home ranges. Spatial distribution of habitats strongly influences habitat ratings; more habitat is rated unsuitable when spatial distribution is taken into account.

The authors recommended that selection of sample unit size for a GIS analysis be based on animal home range size, special habitat requirements, and intended model use. They also recommended spatially explicit models that take into account distribution of habitats. Because marten are known to avoid forest openings, which are rated optimal habitat in the model tested, the results of this study are probably not directly applicable to an analysis or revision of the marten HSI model. However, the recommendation to use spatially explicit models seems appropriate for many types of habitat models, including HSI models.
Suggested revisions: None.

Reference: Ritter, A. F. 1985. Marten habitat evaluation in northern Maine using Landsat imagery. Proceedings of the Northeast Fish and Wildlife Conference 42:156–166.
Synopsis: Ritter developed an HSI model for marten in northern Maine, an area not covered by the HSI model in FWS/OBS-82/10.11. Ritter's model is based on habitat preference data collected from the region and applies to female marten winter habitat. The model contains food and cover components, with softwood-dominated stands given higher values for food and cover than hardwood-dominated stands. The high value for softwood-dominated forest stands is similar to the rating in the USFWS model. However, Ritter's model differs in two ways: (1) both food and cover are considered, and (2) he ranks eight to nine recognized mixes of hardwood and softwood forest stands for each habitat value to rate habitat. Thus, specific components of different forest stands, such as stand age and downed wood cover, were not specifically considered but were probably incorporated when developing ranks. The model was applied to a 13,185-km^2 area of northern Maine using Landsat maps from two different years. The area was divided into 2.2-km^2 blocks that were classified by forest type and rated

with the HSI model. The model was tested using trapping data from 11 randomly selected towns in the area.

The model rated much of the area as very good marten habitat (overall average 0.67 to 0.69). Results were consistent with the high catch of marten in northern Maine. However, neither marten catch per trapper nor marten catch modified by road access and distance to population centers was correlated with habitat ratings from Ritter's model. Ritter thought the lack of fit between his HSI model and trapping data was due to the type of data used for the test, rather than model inaccuracies. He suggested using a more direct estimate of population size, such as tracking data or live-trapping studies. He supports the use of Landsat imagery for habitat evaluation on a large scale.

Suggested revisions: None. However, his suggestion to use a more direct estimate of population size, such as tracking data or live-trapping studies, should be applicable to testing the HSI model.

Moose (Alces alces)

Summarized by: Janelle Corn

Reference: Allen, A. W., J. W. Terrell, W. L. Mangus, and E. L. Linquist. 1991. Application and partial validation of a habitat model for moose in the Lake Superior Region. Alces 27:50-64.

Synopsis: The authors evaluated the validity of several aspects of the dormant-season moose HSI model in Superior National Forest in northeastern Minnesota. They modified the model's dormant-season forage suitability indices to incorporate browse species preference and forest stand species composition, size, and stocking rates. A GIS-based analysis of habitat (area and interspersion) and early-winter aerial surveys of moose in 3 years of varying weather severity were used to test the suitability ratings for distance to dormant-season cover and for dormant-season forage and cover. Habitat characteristics and suitability indices around moose locations were compared with similar data from random points at several spatial scales.

At small spatial scales, moose selected optimal cover, as rated by the model, more often than would be predicted by chance in the two most severe winters. Statistical comparison of forage suitability indices for areas used by moose and random points were not given. The proportion of optimal habitats used by moose increased with increasing winter severity.

Although the model applies to late-winter habitat use, this study evaluated early-winter moose habitat use because aerial surveys can only be conducted at this time. The authors considered this a conservative test of the model. The test was conducted in a forest with a low percentage (5%) of stands in optimal winter cover.

Suggested revisions: For future GIS applications, the authors recommended that estimates of forage biomass for each of the forest cover types, scaled from 0.0 to 1.0, be used to measure forage suitability. They recommended wetland suitability ranking and use of cover type ratings and distance algorithms such as those they developed.

Reference: Hepinstall, J. A. 1992. Application of the Lake Superior region moose habitat suitability index model to an area of the Superior National Forest using a Geographic Information System. M.S. thesis, University of Minnesota, Minneapolis. 116 pp.

Synopsis: Hepinstall applied the model to an area in the Superior National Forest in northeastern Minnesota. He modified model calculations for species composition of growing season browse, dormant-season browse, and dormant-season cover so that values were obtained for each stand in the 600-ha evaluation unit, rather than averaged over the unit as a whole. He also introduced a ranking factor for wetland types, incorporating research conducted since model publication. Using moose track counts, Hepinstall tested the assumptions that browse more than 100 m from cover is of low suitability in winter and that optimal cover adjacent to optimal browse is used more than optimal cover adjacent to poor browse or poor cover adjacent to optimal browse. Moose used browse less than 100 m from cover significantly more than that farther away. Forest stand types were rated similarly by the model and track counts. However, he did not observe greater use of optimal cover-optimal browse pairs than of other possible combinations of cover and browse, and he concluded that the model may be too restrictive in ranking dormant-season cover and browse habitats in mild winters. Hepinstall found that classification of some types of Forest Service stands are prone to errors that have large effects on calculated HSI's. He included some units (those around the edges of the management area) in his GIS analysis for which he did not have complete data and concluded he had unrealistically reduced HSI's in edge units. However, he thought that if the area outside an evaluation area is also outside the control of the Forest Service, it is probably more accurate to calculate HSI's conservatively. Hepinstall did not ground-truth the GIS application to HSI model testing, either for moose use or for accuracy of Forest Service stand data.

Suggested revisions: Evaluate species composition for each stand rather than for the entire evaluation unit, and use more detailed rankings of wetland habitats. Ranks of winter cover and browse habitat suitability should be increased in mild winters. Forest Service data (particularly

classification of some forest stand types) should be used with caution when applying the HSI model.

Pronghorn (Antilocapra americana)

Summarized by: Bruce W. Baker

Reference: Irwin, L. L., and J. G. Cook. 1985. Determining appropriate variables for a habitat suitability model for pronghorns. Wildlife Society Bulletin 13:434–440.

Synopsis: The authors used regression analysis to assess the relative importance of 23 environmental variables in explaining variation in two performance measures: pronghorn densities on winter ranges and fawn:doe ratios. The 23 variables included aspects of vegetation, climate, topography, livestock grazing, development activities, and pronghorn harvest intensities. Simple linear regression was used to evaluate relations among variables, and multiple regression was used to assess the relative importance of independent variables.

Results supported inclusion of three of the five variables in the HSI model. Ranked in order of importance they are shrub canopy cover, topographic diversity, and shrub height. The importance of shrub diversity and availability of winter wheat was not verified, but the variables should still be retained in the model. The pronghorn HSI model should be useful for pronghorn management because important variables (e.g., shrub cover) are under human control. Regional habitat model tests are more robust than intensive local studies because results apply across varied environmental conditions. Variables, other than those in the model, that explained variation (positive or negative correlation) in winter pronghorn densities and fawn:doe ratios included winter precipitation, elevation, aspect, certain cover types, and doe harvest rates.

Suggested revisions: This is a companion paper to the next reference, which contains suggested revisions.

Reference: Cook, J. G., and L. L. Irwin. 1985. Validation and modification of a habitat suitability model for pronghorns. Wildlife Society Bulletin 13:440–448.

Synopsis: The original and a revised pronghorn HSI model were evaluated based on vegetation and topographic data from 29 winter ranges in four states. The performance measure was pronghorn winter density, estimated from 3 to 10 years of data on each winter range. The revised model used modified SI values for shrub canopy cover, topographic diversity, winter wheat availability, and shrub height, as well as a newly derived variable for herbaceous canopy cover. Modifications were based on findings in the previous reference describing 23 environmental variables that might predict pronghorn habitat quality. HSI and SI values for each winter range were regressed against density estimates using simple linear regression with actual and log-transformed data.

The entire original model explained 39% of the variation, with 32% explained by shrub cover alone. A modified log-transformed model explained 70% of the variation. The modified model was valid based on direct evidence from this study and indirect evidence from a previous study (previous summary). Even though most of the variation was related to only two variables, shrub cover and topographic diversity, the authors recommended retaining all six variables in the modified model. Lack of significance for individual variables such as winter wheat might be due to sampling limitations, indicating the full model would be more applicable across a greater variety of conditions.

Suggested revisions: The authors suggested using their revised six variable model and thought it should be particularly suited to assessing habitat impacts over large areas. Because their model does not have a variable addressing snow accumulation, they advised caution in predicting habitat quality in areas where snow may cover vegetation. The model should not be used to predict pronghorn numbers but rather to describe habitat potential.

White-tailed Deer (Odocoileus virginianus)

Summarized by: Brian S. Cade

Reference: Stauffer, D. F. 1990. Field evaluation of an HSI model for white-tailed deer in the Coastal Plain. Unpublished report, Virginia Polytechnic Institute and State University, Department of Fisheries and Wildlife Sciences, Blacksburg.

Synopsis: The author estimated HSI values for models I, II, and III. Model I uses estimates of metabolizable energy (kcal/ha) for seven forage classes: current year twig growth and pine needles; current year fallen leaves from perennial woody species; leafy browse in situ; mast, including acorns, fruits, and seeds from cultivated crops; leguminous seeds; cool-season grasses and forbs; and fungi. Model II uses estimated weights and digestibility of each forage with suitability indices, and Model III uses estimates of forage weights and density of mast trees. Eight study sites in Louisiana, Mississippi, Alabama, South Carolina, North Carolina, and Virginia were used to represent a range of Coastal Plains habitats thought to range from poor to excellent. For all three models, HSI values were always 1.0 at all sites. Sites were often rated as having 30 to 40 times the necessary available energy required to be optimum. Current year leaves contributed 3,238,000 to 4,179,000 kcal/ha, far exceeding the

required 100,000 kcal/ha for an HSI = 1.0. The original model was insensitive to variation in metabolizable energy from the diversity of forage types.

Suggested revisions: Revised percent digestible dry matter and percent utilization rates are as follows: 55% digestible dry matter (5% utilization) for current annual growth, 60% (0.5%) for current year leaves, 55% (20%) for leafy browse, 68% (50%) for mast, 63% (20%) for cool-season herbs, and 95% (50%) for fungi. Revised HSI model output varied from 0.27 to 1.0 for Model I, but there was low correlation with biologists' rankings of the sites (-0.26, $P = 0.104$).

Reference: Harper, K. C. S. 1990. An evaluation of a habitat suitability index for white-tailed deer in east Texas. M.S. thesis, Stephen F. Austin State University, Austin, Texas. 43 pp.

Synopsis: Estimates of forage for Model III in 3–4, 5–9, and 11–15-year-old pine plantations and riparian habitats were compared with percentage deer locations (obtained by radiotelemetry) in each habitat. HSI values in 1989 were 0.90, 0.42, 0.09, and 0.12, and in 1990 they were 0.18, 0.12, 0.08, and 0.10 for youngest pine to riparian zone habitats. Cool-season grasses and forbs contributed most to differences in available forage and HSI between 1989 and 1990. Regression equations for ocularly estimated weights and wet weights of forage were developed for the various forage categories. HSI and percentage of telemetry locations were poorly correlated, -0.32 for 1989 and 0.20 for 1990.

Suggested revisions: General recommendations were to use wet weights rather than dry weights of forage, to require specified sample sizes for estimates, and to modify utilization rates of forages based on diet preferences.

Reference: Banker, M. E. 1994. Modeling white-tailed deer habitat quality and vegetation response to succession and management. M.S. thesis, Virginia Polytechnic Institute and State University, Blacksburg. 148 pp.

Synopsis: Indices from the HSI model and modifications to the HSI model were compared with condition indices for 1.5-year-old bucks harvested in 11 management units on Quantico Marine Base. Indices from the original model were not strongly correlated with body weight (Spearman's $r = -0.40$, $P = 0.221$), beam diameter (Spearman's $r = 0.06$, $P = 0.851$), beam length (Spearman's $r = 0.37$, $P = 0.265$), or number of points (Spearman's $r = -0.24$, $P = 0.473$). Area within each management unit with an HSI > 0.5 was weakly correlated (Spearman's $r = 0.49$, $P = 0.129$) with beam diameter and length. There was little variation in HSI across the 11 management units based on the estimates of available energy in forages. The original model provided optimal indices (HSI = 1.0) in all habitats, whereas a modification that eliminated leaves and ground pine in forage estimates provided indices ranging from 0.73 to 0.87. The modified model provided little improvement in correlations with body condition indices.

Suggested revisions: This evaluation and that of Stauffer (previous summary) suggested that the original HSI model erroneously rates forage as optimal in all habitats because it fails to account for digestibility values and utilization rates. The author agrees with Stauffer's suggested modifications for incorporating new digestibility of dry matter percentages.

Summaries of Habitat Suitability Index Model Evaluations for Birds

Black-capped Chickadee (Parus atricapillus)

Summarized by: Richard L. Schroeder

Reference: Bayer, M., and W. F. Porter. 1988. Evaluation of a guild approach to habitat assessment for forest-dwelling birds. Environmental Management 12(6):797–801.

Synopsis: The relation between the HSI and chickadee abundance was evaluated using data from four counts at each of four survey points in seven sites in 1984 and 1985. Bird abundance was converted to a relative abundance index (RAI) by dividing abundance at each survey point by maximum abundance for each species. This index was presumed indicative of habitat quality and equivalent to the model HSI. The model was tested at continuous and discrete levels of habitat quality. Discrete categories were RAI ≥ 0.5, $0 < \text{RAI} < 0.5$ and RAI = 0. A two-tailed, paired-sample *t*-test was used to determine if there was a difference between the HSI's and RAI's. The chickadee HSI model accurately predicted habitat quality at the discrete level ($P \leq 0.05$), but not at the continuous level ($P \geq 0.05$).

Suggested revisions: None.

Reference: Romary, C. L. 1990. Evaluation of the habitat suitability index models for the black-capped chickadee and downy woodpecker. M.S. thesis, Emporia State University, Kansas.

Synopsis: Chickadee abundance data from 25 impact and 25 control sites in riparian habitat in eastern Kansas were compared with site HSI's. No relation was found between chickadee density and HSI. However, the sampling methods used to measure the reproductive component of the model (snag density) were not adequate. The food component of the black-capped chickadee HSI model was

analyzed by assessing the upper limits of the species' response. The highest values for each of 10 categories of the food SI were significantly related to chickadee densities ($r = 0.93$, $P < 0.005$).

Suggested revisions: The reproductive component of the model could possibly be improved by adding decay classes for snags and evaluating the presence of suitable chickadee cavities in nonsnag trees.

Reference: Schroeder, R. L. 1990. Test of a habitat suitability index model for black-capped chickadees. U.S. Fish and Wildlife Service Biological Report 90(10). 8 pp.

Synopsis: A model assumption and the relation between the HSI and chickadee densities were tested. The model assumption that tree canopy volume can be predicted by measuring tree height and canopy closure was tested in 18 plots in plains cottonwood (*Populus sargentii*) bottomland along the South Platte River in northeast Colorado. Although there was a linear relation ($r^2 = 0.70$) between the two methods of predicting tree canopy volume, the fit model varied significantly from the ideal proposed model. The two SI curves for tree canopy closure and tree height and the food SI calculation were modified. Statistical analyses of these revised model variables produced an improved linear relation ($r^2 = 0.877$), with no significant difference between the slope of the fitted model and the proposed ideal model. In addition, measures of basal area, although not a part of the original HSI model, were shown to be good predictors of tree canopy volume.

The HSI test used black-capped chickadee density data from 10 individual 16-ha riparian cottonwood plots and analyzed the original model and the model with the revised food SI described above. Least absolute deviations regression of chickadee densities against the HSI for the original and revised models indicated that neither model differed significantly from a zero slope. The HSI values were also tested against a proposed ideal model, using estimates of maximum expected chickadee abundance. In this case, the original model failed, but the revised model indicated no significant difference from the slope of the proposed ideal model. Three possible explanations of these results are discussed, and additional studies are recommended.

Suggested revisions: Modify the SI curves for tree canopy closure and tree height, as well as the formula used to determine the food SI value. The original model used the number of snags from 10 to 25 cm dbh as a measure of nest site availability. The best overall measure may be the combined density of the number of trees (≥ 10 cm dbh) with ≥ 1 cavity and the number of snags (≥ 10 cm dbh).

Canvasback (Aythya valisineria)

Summarized by: Tom Stanley

Reference: Johnson, D. H., M. C. Hammond, T. L. McDonald, C. L. Nustad, and M. D. Schwartz. 1989. Breeding canvasbacks: A test of a habitat model. Prairie Naturalist 21(4):193–202.

Synopsis: The canvasback HSI model was tested in a retrospective study using survey data collected mostly in 1965 and 1967 from 2,265 wetlands in North Dakota, South Dakota, and Minnesota. Data for wetland size (SIV2) and water regime (SIV3) were available for each wetland, but values for emergent vegetation (SIV1) had to be estimated from the survey data by converting categorical values to numerical values. Waterfowl counts for each wetland were made during a single survey conducted in early May.

Canvasbacks were observed on only 36 of the 2,265 wetlands. Correlation of canvasback pair densities with HSI values revealed there was no relation between the variables ($r = 0.0023$, $P = 0.91$). Wetlands were grouped into 21 categories according to their HSI values: HSI = 0, $0 < \text{HSI} \leq 0.05, \ldots, 0.95 < \text{HSI} \leq 1.00$, and the maximum canvasback density in each category was computed. If the HSI model predicts the potential of the habitat to support canvasbacks, then habitats with high HSI values could have either high or low canvasback densities. The wetlands with the lowest HSI values had the highest maximum densities of canvasbacks, the opposite of what should have occurred. However, low sample sizes in groups with higher HSI values may have biased this result. The authors concluded that the HSI model was of no value for predicting the density of breeding canvasbacks in the sampled wetlands.

Suggested revisions: The authors suggested two areas where the model might be improved: (1) include a variable describing the pattern of emergent vegetation in the wetland, and (2) include a variable that accounts for interactions between wetland size and permanency.

Downy Woodpecker (Picoides pubescens)

Summarized by: Richard L. Schroeder

Reference: Bayer, M., and W. F. Porter. 1988. Evaluation of a guild approach to habitat assessment for forest-dwelling birds. Environmental Management 12(6):797–801.

Synopsis: The methods used were the same as described for this study for black-capped chickadee. The downy

woodpecker HSI model did not accurately predict habitat quality at either the continuous or discrete levels ($P \geq 0.05$). The authors could not rule out inadequate censusing procedures as a major contributor to variation for downy woodpecker abundance. Detection of individuals was based primarily on sound; woodpeckers may provide sound cues too infrequently to survey their abundance with this technique.
Suggested revisions: None.

Reference: Romary, C. L. 1990. Evaluation of the habitat suitability index models for the black-capped chickadee and downy woodpecker. M.S. thesis, Emporia State University, Kansas.
Synopsis: Downy woodpecker density at 25 riparian habitat sites in eastern Kansas was compared with site HSI's; no relation was found. The author noted the following weaknesses in his methods: sampling methods to measure snags were inadequate, observer confusion may have existed in identifying downy versus hairy woodpeckers, and sampled area was too small relative to the woodpecker's home range and scarcity. The lack of a relation between estimated woodpecker densities and the HSI could be as much due to inadequate census techniques as to inaccuracies in the model.
Suggested revisions: None.

Forster's Tern (Sterna forsteri)

Summarized by: Carroll L. Cordes

Reference: Martin, R. P. 1993. Habitat suitability index models: Forster's tern (breeding)--Gulf and Atlantic coasts (revised). Unpublished report, Louisiana Nature Conservancy, Baton Rouge.
Synopsis: The author revised the published model based on a review of literature for the Forster's tern and related species and identified key references to support the revisions.
Suggested revisions: Model variables V1, V3, and V4 were modified, and minor editorial changes were made to the original text. For variable V1, any area with less than 50% coverage of vegetation (*Spartina alterniflora* or *S. patens*) should have a suitability index of 0. The optimal size of a nesting island was identified to range from 1.1 to 5.0 ha, with smaller and larger islands having lower suitability for nesting terns. For variable V4, a distance of 4 and 6 km from the mainland or from another island larger than 20 ha should have a suitability index of 1.

Great Blue Heron (Ardea herodias)

Summarized by: Richard L. Schroeder

Reference: Corley, B. A., W. L. Fisher, and D. M. Leslie, Jr. 1995. GIS-based validation of the habitat suitability index model for the great blue heron. Final report, Oklahoma Cooperative Fish and Wildlife Research Unit, Stillwater. Unit Cooperative Agreement No. 14-16-0009-1554, Research Work Order No. 13. Final report.
Synopsis: The relation between the reproductive index and the presence of active great blue heron rookeries was evaluated for 18 rookeries in the south-central Great Plains. The model output for these sites was either 0.0 or 1.0; there were no intermediate values. The reproductive index identified only 3 of the 18 rookeries as suitable habitat for reproduction, was not related ($P > 0.10$) to rookery population size, and was not a reliable predictor of suitable nesting habitats in Oklahoma.
Suggested revisions: Revisions were developed based on height, diameter, and crown dimensions of potential nest trees; the distance of potential nest trees to water; and revised distances to various human disturbances. There were no significant relations between any of the revised variables or the revised reproductive index and measures of great blue heron rookery population size.

Greater Sandhill Crane (Grus canadensis tabida)

Summarized by: Bruce W. Baker

Reference: Baker, B. W., B. S. Cade, W. L. Mangus, J. L. McMillen, and F. J. Dein. Multi-scale evaluation of a suitability model for sandhill crane nesting habitat. Unpublished report, Midcontinent Ecological Science Center, Fort Collins, Colorado.
Synopsis: Data were collected at Seney National Wildlife Refuge in northern Michigan. GIS analysis compared HSI's around nest sites (used) and random sites (available). HSI's and SI's for individual habitat components were compared for circular buffers around nest sites and random sites. Two of these buffers were based on proportions of the average home range of crane chicks at Seney (157.9 and 55.1 ha), and three were selected arbitrarily (12.6, 3.1, and 0.8 ha). Habitat classification was based on the National Wetlands Inventory system, although mapping resolution was more detailed. Results should apply to the entire range of the greater sandhill crane.

An HSI value of 0.37, which was lower than expected, was calculated using the original model by

simply averaging the upland and wetland values, rather than using an average weighted by some variant of relative area. For example, an area with 99% cropland (SI = 1.0) and 1% emergent wetland (SI = 1.0) yields an HSI of 0.51, whereas an area of 99% emergent wetland and 1% forestland (SI = 0.1) yields an HSI of 0.39.

Cranes selected nest sites in proportion to availability for all five buffer scales evaluated, based on overall HSI values. However, selection for specific habitat components described in the model did occur. In a companion paper, Baker et al. (1995) showed nests were placed in or near emergent wetlands and in the seasonally flooded water regime, both highly rated by the crane model. Nests were located away from upland forests, which also supports the model. However, there was no habitat selection beyond 200 m from a nest. Beyond this distance, the analysis was inconclusive, in part because larger buffer scales increased heterogeneity and overlap among nests and random buffers. Evaluation at the larger scale of an entire marsh (comparing crane use at several marshes differing in habitat quality) instead of at the scale of nest territory might be a more appropriate test of the model and would more closely approximate its intended application in management and permitting situations.

Suggested revisions: Upland value should be given less weight in areas where diverse wetlands can meet all life requisites. The relative importance of uplands and wetlands is dependent on their value and relative area.

Greater White-fronted Goose (Anser albifrons)

Summarized by: Carroll L. Cordes

Reference: Orthmeyer, D. L. 1994. Evaluation of a habitat suitability model: Greater white-fronted geese (wintering). Unpublished report, National Biological Survey, Northern Prairie Science Center, California Field Station, Dixon.

Synopsis: Orthmeyer compared model scores against goose use of five habitat (crop) types across three periods during winter in California. Study sites were located in the Sacramento Valley and the Sacramento-San Joaquin River delta. The variable used to assess habitat suitability was the proportion of the study areas represented by agricultural lands preferred by wintering geese.

HSI scores under-represented the importance of California wintering habitats for white-fronted geese. The model failed to account for temporal variation in habitat availability and use by wintering geese. Model scores, however, did indicate that the Sacramento Valley was more suitable as habitat for geese than the Sacramento-San Joaquin River delta.

Suggested revisions: Several modifications are presented to make the model more applicable in the southern United States, northern Mexico, and California. To make the model more useful over a wider geographic range, include the following assumptions: period of model application is through April; model is applicable in the southern United States, northern Mexico, and California; and natural wetland areas for roosting and feeding geese are available.

Several recommendations were made for improving overall model performance. (1) The model should be structured for use over three time periods during "winter"-early (September to November), mid (December to January), and late (February to April). This modification is recommended so that the model is more responsive to temporal changes in habitat suitability during the winter period. (2) Corn, barley, and oats should be included in the model as preferred agricultural habitats, especially for areas where rice is absent. (3) Harvested rice fields should be divided into two classes: wet and dry. This modification was based on evidence that geese prefer harvested dry rice over harvested wet rice fields in California. (4) The model would be more efficient if fallow fields or rangeland and winter pasture habitat types were omitted because these habitat types are neither preferred nor used much by white-fronted geese throughout their winter range in the United States. (5) A green-growth habitat type (e.g., green winter pasture, winter wheat) should be included in lieu of the cultivated-plowed habitat type in the current model. (6) The wetlands model should be deleted and an assumption involving wetlands included in the revised model.

Laughing Gull (Larus atricilla)

Summarized by: Carroll L. Cordes

Reference: Hardaway, T. E. 1993. Habitat suitability index models: Laughing gull (revised). Unpublished report, National Biological Survey, Southern Science Center, Lafayette, Louisiana.

Synopsis: The author prepared an updated version of Biological Report 82(10.94). New references were added based on post-1985 literature for the laughing gull and related species.

Mallard (Anas platyrhynchos)

Summarized by: Carroll L. Cordes

Reference: Twedt, D. J., M. W. Brown, and J. R. Nassar. 1993. Habitat suitability index models: Mallard (winter habitat, Lower Mississippi Valley). Unpublished report, National Biological Survey, Southern Science Center,

Mississippi Valley Research Field Station, Vicksburg, Mississippi.

Synopsis: Mallard densities obtained from aerial surveys were compared with habitat suitability indices derived from satellite imagery. For 25 sampling units in west-central Mississippi, southeast Arkansas, and northeast Louisiana land cover was classified as forest, nonforest, or one of six agricultural classes. Mallard densities were estimated within each 256-km^2 sampling unit by aerially surveying 25% of the area using randomly selected transects.

A regression model was used to predict mallard densities from habitat suitability indices. The published HSI model accounted for little of the variability in the data, and was a poor predictor of wintering mallard density in the Mississippi alluvial valley.

Suggested revisions: Because mallards are highly mobile, the model should be revised by increasing the temporal and spatial framework to provide a better reflection of each area's suitability to support wintering mallards. Food availability in forested wetlands was the most important component of the food availability index, and emphasis should remain on quantifying this component of habitat. Flood conditions directly influence wintering mallard densities, but the presence of flood water during any single HSI evaluation period may not be indicative of the long-term flood potential of an area. A more cost-effective and consistent approach to determine flood conditions is to reconstruct the recent historic pattern of flooding within the Mississippi alluvial valley from a series of years with different flood conditions. From such data, a flood probability value would be assigned to each area being evaluated for mallards.

Northern Bobwhite (Colinus virginianus)

Summarized by: Brian S. Cade

Reference: O'Neil, L. J. 1993. Test and modification of a northern bobwhite habitat suitability index model. U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report EL-93-5. 106 pp.

Synopsis: HSI values for nine study sites on the Ames Plantation, Grand Junction, Tennessee, were compared with estimates of birds per hectare from a December 1983 walking census. Density ranged from 0 to 3.3 birds/ha, and HSI ranged from 0.19 to 1.00. Density and HSI were correlated ($r = 0.58$, $P < 0.10$), but scatter plots revealed HSI's overestimated densities for seven of nine sites. Variables related to the food component were responsible for high indices. Spatial interspersion of nesting, food, and winter components of the HSI model were high and not limiting.

Suggested revisions: A revised model that produced a better correlation between HSI and density ($r = 0.75$, $P < 0.02$) included changing the equivalent optimum area of food to 90%, setting minimum SI for food plants and bare ground at 0.05, setting optimum levels of mast and bare ground at 50–60%, and changing the equation for food to ((SI food plants x SI bare ground)$^{0.05}$ + SI mast)/2. Six of nine sites still had HSI's that overestimated density, although not by as much as the original model. Several other model revisions were investigated but not recommended.

Reference: Tonkovich, M. J. 1995. Field evaluation of the northern bobwhite habitat suitability index model with implications for the Conservation Reserve Program. Ph.D. thesis, Virginia Polytechnic Institute and State University, Blacksburg.

Synopsis: A modified version of the HSI model was applied at 121 50.2-ha circular sites and compared with spring whistle counts for 6 years (1986 to 1991). Rank correlation between HSI's and whistle count indices was -0.20 ($P = 0.03$). Winter food was the limiting model component at 117 of the 121 sites. Optimum equivalent area of winter food was negatively correlated with whistle count indices ($r = -0.24$, $P = 0.01$), as was optimum winter cover ($r = -0.41$, $P = 0.001$). Optimum equivalent area of nest and brood cover was positively correlated with whistle count indices ($r = 0.44$, $P = 0.001$). Whistle count indices increased with an increase in optimum nest brood cover up to 35%. Telemetry data indicated heavily used areas within quail home ranges had greater winter food than unused areas. Because conservation practices implemented under the Conservation Reserve Program in the study area were eliminating agricultural crop sources used as winter food, the impact on quail probably will be negative. Attempts to improve the model fit by changing the winter food component were futile.

Pileated Woodpecker (Dryocopus pileatus)

Summarized by: Richard L. Schroeder

Reference: Bayer, M., and W. F. Porter. 1988. Evaluation of a guild approach to habitat assessment for forest-dwelling birds. Environmental Management 12(6):797–801.

Synopsis: The methods used were the same as described for this study for the black-capped chickadee. The pileated woodpecker HSI model did not accurately predict habitat quality at the continuous or discrete level ($P \geq 0.05$). The authors could not rule out inadequate censusing procedures as a major contributor to variation for pileated woodpecker abundance. Detection of individuals was

based primarily on sound and woodpeckers seem to provide sound cues too infrequently to survey their abundance with this technique.
Suggested revisions: None.

Reference: Lancia, R. A., and D. A. Adams. 1985. A test of habitat suitability index models for five bird species. Annual Conference Southeastern Association Fish and Wildlife Agencies 39:412–419.
Synopsis: Limited tests of a model for the pileated woodpecker were conducted in eastern North Carolina. The report does not specify if the published version of the HSI model was used. Each model was reviewed and, when necessary, adapted to conditions on the study area. Bird census data were collected March 17–23 and April 6–18, 1983, and probably represented breeding and transient individuals. Habitat and bird census data were recorded on 67 of 81 possible points, with no sampling done on points with impenetrably dense vegetation. There was no significant relation between HSI and relative densities of pileated woodpeckers. I believe poor model performance was probably due more to the inappropriate sampling scales or low number of observations than to the model itself.
Suggested revisions: None.

Pine Warbler (Dendroica pinus)

Summarized by: Richard L. Schroeder

Reference: Lancia, R. A., and D. A. Adams. 1985. A test of habitat suitability index models for five bird species. Annual conference of the Southeastern Association Fish and Wildlife Agencies 39:412–419.
Synopsis: Methods are the same as described for the reference for pileated woodpecker. There was a significant positive relation ($r^2 = 0.87$, $P = 0.067$) between the HSI and relative densities of pine warblers. The report did not test the model in FWS/OBS-82/10.28 REVISED.
Suggested revisions: None.

Plains Sharp-tailed Grouse (Tympanuchus phasianellus jamesi)

Summarized by: Brian S. Cade

Reference: Prose, B. L. 1992. Heterogeneity and spatial scale in nesting habitat selection by sharp-tailed grouse in Nebraska. M.S. thesis, Colorado State University, Fort Collins. 72 pp.
Synopsis: Residual vegetation cover was quantified using aerial photo interpretation of nested 1-, 2-, 4-, 8-, and 16-ha quadrats surrounding 38 sharp-tailed grouse nests and 38 random locations in the Sandhills of Nebraska. Grouse nested where mean effective heights (visual obstruction readings from a Robel pole) were greater than random locations at all spatial scales. Patches of tall vegetation were larger at nests than at random locations in the 8- and 16-ha quadrats. The HSI model rates mean effective heights ≤5 cm as unsuitable habitat, but quadrats around nest sites had mean effective heights ranging from 2.7 to 3.9 cm. Patches of robust vegetation in the Sandhills rarely exceeded 10 cm in mean effective height, half the 20-cm value described as optimal nesting habitat in the HSI model. Disparities between this study and others are probably due to the bunchgrass community of the Sandhills and previous investigations of sharp-tailed grouse nesting habitat failing to quantify residual cover over larger areas of habitat.
Suggested revisions: Based on plots of mean effective heights of residual cover in 16-ha quadrats around grouse nests and a logistic regression comparing nest and random locations, a revised suitability curve for nesting habitat was developed. Suitability of residual cover to provide nesting habitat is zero for mean effective heights ≤2.6 cm and becomes optimum (1.0) at mean effective heights ≥3.4 cm. Cautions about extrapolating these changes to other vegetation communities are provided.

Ruffed Grouse (Bonasa umbellus)

Summarized by: Brian S. Cade

Reference: Hammill, J. H., and R. J. Moran. 1986. A habitat model for ruffed grouse in Michigan. Pages 15–18 *in* J. Verner, M. L. Morrison, and C. J. Ralph, editors. Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison.
Synopsis: Number of breeding male territories on five study sites in Michigan and Wisconsin predicted by a modified version of the HSI model were compared with observed number of territories. Observed counts were based on 1 to 6 years of surveys. Predicted and observed (in parentheses) number of territories were 78.0 (101.0), 35.5 (35.0), 26.0 (32.0), 8.8 (7.0), and 45.7 (30.0), yielding an average percent error of 6% underestimation. The study did not specifically describe how HSI values were converted to number of territories. The tested model was sensitive to proposed forest management practices in Michigan.
Suggested revisions: The tested model modified the equivalent stem densities for regenerating shrubs and conifers, eliminated the penalty for conifer cover, and assumed mature aspen for winter food was always available.

Veery (Catharus fuscescens)

Summarized by: Richard L. Schroeder

Reference: Bayer, M., and W. F. Porter. 1988. Evaluation of a guild approach to habitat assessment for forest-dwelling birds. Environmental Management 12(6):797–801.
Synopsis: The methods used were the same as described for this study for black-capped chickadee. The veery HSI model accurately predicted habitat quality at the discrete level ($P \leq 0.05$) but not at the continuous level ($P \geq 0.05$).
Suggested revisions: None.

White Ibis (Eudocimus albus)

Summarized by: Carroll L. Cordes

Reference: Valentine, J. M., Jr. Habitat suitability index models: White ibis (revised). Unpublished report, National Biological Survey, Southern Science Center. Lafayette, La.
Synopsis: Valentine reviewed the original model for white ibis and compared habitat relations and life history requirements with more recent information published since model release. He also added some key references.
Suggested revisions: Valentine concluded that recent publications on white ibis did not provide data or findings that would warrant changes to the original HSI model variables and SI curves.

Williamson's Sapsucker (Sphyrapicus thyroideus)

Summarized by: Bruce W. Baker

Reference: Conway, C. J., and T. E. Martin. 1993. Habitat suitability for Williamson's sapsuckers in mixed-conifer forests. Journal of Wildlife Management 57(2):322–328.
Synopsis: Study sites were snowmelt drainages of conifer-aspen (*Populus tremuloides*) and intervening ridges of ponderosa pine (*Pinus ponderosa*). Four habitat variables from the model were compared at 33 nest sites and 66 nonuse sites (33 within the drainage and 33 on the slope or ridge adjacent to the drainage) in the mountains of central Arizona. Variables were percent canopy cover, percent of canopy dominated by aspen, dbh of overstory aspen trees, and density of suitable snags. Authors evaluated 4-ha patches around each site to test the HSI model, using nest presence as the performance measure.

HSI values were greater for nest sites than for nonuse sites outside of drainages; there were no differences between nest and nonuse sites within drainages. In other words, the model correctly predicted that Williamson's sapsuckers preferred to nest in drainages rather than on ridgetops, but it could not distinguish between used and nonused sites within drainages.
Suggested revisions: The dbh of overstory aspen trees had no significant influence on HSI; future models should be more liberal in defining what is considered an overstory aspen in relation to other canopy. New models should continue to stress snag density but should consider aspen snags, including values for height and diameter, separately from other snags. The authors did not quantify these general suggestions or test them at new sites.

Yellow Warbler (Dendroica petechia)

Summarized by: Bruce W. Baker

Reference: Baker, B. W., D. L. Hawksworth, and J. G. Graham. 1992. Wildlife habitat response to riparian restoration on the Douglas Creek watershed. Pages 62–80 *in* Proceedings of the Colorado Riparian Association, November 4–6, Steamboat Springs.
Synopsis: HSI values on 200- x 1,000-m transects were compared with adult breeding density at 11 locations in the Douglas Creek watershed of northwestern Colorado. HSI values were computed for plant community polygons mapped from aerial photos and entered in a GIS. SI values were based on species composition of shrubs within a polygon and their height and canopy cover. HSI values were computed as a composite of all SI values of each polygon within a transect.

Because saltcedar (*Tamarix pentandra*) was a common exotic invader and of questionable value to yellow warblers, and because it is a hydrophytic plant that rates equal in value to willow in the model, the authors modified the original model by considering saltcedar as a nonhydrophytic plant.

Preliminary correlations showed that yellow warbler density increased with increasing HSI values, although the analysis was not complete and associated statistics not reported. Correlation improved when saltcedar was considered a nonhydrophytic plant and when only the riparian channel data were used.

High yellow warbler densities occurred in a beaver pond ecosystem with poor willow habitat. This occurrence may have been due to adjacent nonhydrophytic shrub habitat that could be used as a nesting area when in association with beaver ponds that provided food. This

exception to the model may be limited to unusual study site conditions.

Suggested revisions: The yellow warbler HSI model probably functions adequately; however, some adjustments may be needed to reduce the habitat value of less-preferred hydrophytic deciduous shrubs (saltcedar).

Summaries of Habitat Suitability Index Model Evaluations for Fishes

American shad (Alosa sapidissima)

Summarized by: James W. Terrell

Reference: Ross, R. M., T. W. H. Backman, and R. M. Bennett. 1993. Evaluation of habitat suitability index models for riverine life stages of American shad, with proposed models for premigratory juveniles. U.S. Fish and Wildlife Service, Biological Report 14. 26 pp.

Synopsis: The authors developed an HSI model for juveniles in riverine habitats and evaluated available HSI models for spawning adults and the egg-larval life stage using field data collected over a 3-year period (1990–1992). The HSI was compared to fish abundance as estimated by adult spawning activity, plankton and drift net samples of eggs and larvae, and underwater counts and seine catch per unit effort of juveniles in the Upper Delaware River. The influence of physical habitat variables on these various indices of abundance varied by habitat type. Juvenile abundance was correlated with water temperature, DO, river depth, and turbidity. The authors concluded that American shad models could be applied, with caution, on a comparative basis among river systems.

Suggested revisions: In addition to new models for juveniles in nursery habitat, there are detailed recommendations for revising published models, especially variables related to water temperature.

Reference: Ross, R. M., R. M. Bennett, and T. W. H. Backman. 1993. Habitat use of spawning adult, egg, and larval American shad in the Delaware River. Rivers 4:226–238.

Synopsis: This study is based on the same data as the previous reference. Simple linear regression analysis was used to relate spawning splashes to the five physical habitat variables in the published model. The authors also used regression analysis to define relations between American shad egg and larval densities to six physical habitat variables (sample depth, river depth, temperature, DO, current, and turbidity). Seven distinct habitat types were identified for sampling, and a variety of egg and larval sampling gear (including drift nets, bongo nets and a benthic sled) was employed. Published suitability index graphs were superimposed on plots of fish performance (e.g., number of spawning splashes, number of eggs per cubic meter of water) to determine if maximum SI's described habitat conditions associated with maximum performance. The authors believed that the results of their study generally supported suitability indices for spawning adults, eggs, and larvae as long as some modifications were made to some indices.

Suggested revisions: The maximum value for an SI of 1.0 for temperature for spawning adults should be increased to 24.5°. The optimum value for current velocity for spawning adults should be 0–0.07 m/sec. The upper limit for maximum suitability for water temperature for larvae should be at least 26.5° C.

Arctic Grayling (Thymallus arcticus)

Summarized by: Jeanette Carpenter

Reference: Reynolds, J. B. 1989. Evaluation of the HSI model for riverine Arctic grayling in relation to Alaskan project impacts. Unit Contribution Number 32, Alaska Cooperative Fishery Research Unit, University of Alaska, Fairbanks. Cooperative Agreement Number 14-16-0009-1532, Research Work Order Number 13. 23 pp.

Synopsis: The original model was literature based without verification using field data. Reynolds used professional judgment to evaluate each variable in the model with respect to assumptions for inclusion in the model. He also rated each variable based on responsiveness to eight project impacts common to Alaskan streams, and recommended new variables responsive to project impacts.

Maximum water temperature in summer spawning areas (V1) would be sensitive only to extreme impacts. The maximum value for V2 (average minimum DO in summer) is too low for Alaskan streams. Natural flood events will mask project impacts with respect to V5 (velocity over spawning areas). Although V9 (annual spring access to spawning streams) is a critical habitat feature, it may be impractical because several years of data would be required, and behavior of the species complicates the variable's usefulness. Similarly, V10 (winter habitat) is an important feature, but it is only useful for impacts that occur in winter, the SI is unresponsive to moderate changes, and there are unknown impacts to the species in other seasons. Reynolds had no cautions for three variables: spawning substrate (V3 and V4) and percent of spawning areas available as backwater for nurseries (V6).

Subjective ratings of each variable and the HSI model for responsiveness to Alaskan project impacts indicate

the model is unrelated to impacts from culverts, water removal, and placer mining; indirectly related to impacts from gravel removal, stream channelization and bank stabilization, land clearing, and thermal/sewage effluent; and directly related to dam impacts. For the model to be directly related to all eight impacts, some key variables should be added to or substituted in the model.
Suggested revisions: Reynolds provided SI's for four new variables: turbidity, summer habitat diversity, water velocity, and spawning delay. For a given project impact, he noted which variables should be considered for inclusion in the model. The HSI is the lowest SI score of any variable, as in the original model.

Atlantic Salmon (Salmo salar)

This species is not in the HSI model series.

Summarized by: Jeanette Carpenter

Reference: Trial, J. G., and J. G. Stanley. 1984. Calibrating effects of acidity on Atlantic salmon for use in habitat suitability models. Completion report, Project A-054-ME, Land and Water Resources Center, University of Maine, Orono. 37 pp.
Synopsis: Lab experiments and field observations were used to develop and test an Atlantic salmon HSI model for predicting reductions in habitat quality due to acid precipitation. Parr exposed to several pH levels preferred an average temperature of 14.5°C and selected the highest oxygen concentration available regardless of pH; thus, pH had no effect on oxygen and temperature preferences. In a second experiment, fish obtained from Pollard Brook were used to determine if pH selection and control altered parr behavior. The test fish did not regulate pH to a common preferendum. The third experiment examined interactions between calcium and low pH and their effects on swimming performance of hatchery parr. As pH decreased, critical swimming speeds decreased. Adding calcium improved swimming performance.

Microhabitat (depth, velocity, and substrate use) in Bowles Brook and Old Stream was compared based on snorkeling observations. Parr used average velocity similarly between streams; however, parr in Old Stream used deeper water and more sandy substrates. Fry in Old Stream used deeper and faster water than fry in Bowles Brook. In Old Stream, parr and fry used microhabitat differently. Sample sizes were not provided for the field observations.

Data from these lab and field studies, as well as from other studies, were used to develop an HSI model using a limiting factor approach for a water quality component and geometric means for physical habitat. The model was field tested using electrofishing data from Old Stream, Pollard Brook, and Bowles Brook. Differences between the HSI values with and without pH data indicate the model is too sensitive to pH. Without the pH variable, observed densities correlated well with HSI. When the pH variable was included, observed fish densities did not reflect predicted carrying capacities.
Suggested revisions: None. However, in 1995 the authors published a restructured model (synopsized at the end of this section) that reduced the importance of pH and included a general and specific component for reproduction.

Reference: Trial, J. G. 1989. Testing habitat models for blacknose dace and Atlantic salmon. Ph.D. dissertation, University of Maine, Orono. 128 pp.
Synopsis: Suitability indices were tested by comparing the distribution of suitabilities for sites selected by individual fish with the distributions of the points on the SI curves. Locations of individual fish (134 fry and 43 parr) were obtained by snorkeling and electrofishing in Maine streams from 1981 to 1983. Habitat data collected at each fish location were used to calculate SI's for each fish. Kolmogorov goodness-of-fit tests were used to determine differences between empirical and hypothesized SI distributions. Test results indicated that all of the empirical distributions were less than the hypothetical distributions. Thus, the fish used a narrower range of velocity, substrate, and depth than predicted by the SI values. The SI's overestimated optimal ranges of habitat variables.

Observed distributions of component indices (CI's) derived from locations of individual fish were narrower than the expected distributions calculated from SI's. Component indices developed by joint probabilities or geometric means resulted in identical rank correlations. Therefore, the two calculation methods did not affect site rankings.

Ten years of data from 16 sites in the St. John River in New Brunswick, Canada, and previously published SI's were used to formulate and test four alternative HSI models. The ranks of CI's calculated with the models correlated with fry density ranks. However, the parr CI's and HSI's from the models were not correlated with observed parr densities. Instream cover may be important to parr and may need to be included in parr habitat models. Ranks of water quality CI's were not correlated with ranks of observed densities. Three of the four tested models predicted relative habitat quality.

Internal logic of the models was tested using a classification of environmental factors, including interactions. In general, internal logic and assumptions were considered sound. However, the assumptions in several of the water quality SI's are questionable; a detailed description of a revised model is provided.

Suggested revisions: Primary changes are to the water quality SI's in the model by Trial and Stanley summarized at the beginning of this section.

Reference: Trial, J. G., C. S. Wade, and J. G. Stanley. 1984. HSI models for northeastern fishes. Proceedings of a workshop on fish habitat suitability index models. U.S. Fish and Wildlife Service Biological Report 85(6):17–56.
Synopsis: Problems impeding development of HSI models include scarcity of data on variables that limit the distribution and abundance of species. Observed values for habitat variables are often descriptive and not linked to a response variable such as standing stock, survival, growth, or reproduction.
Suggested revisions: None.

Reference: Moreau, D. A., and J. R. Moring. 1993. Refinement and testing of the habitat suitability index model for Atlantic salmon. Final report to the U.S. Fish and Wildlife Service, Silvio O. Conte Anadromous Fish Research Center. Agreement No. 14-16-0009-1557, Work Order 22. 50 pp.
Synopsis: The model focuses on the habitat characteristics of adult holding pools during migration. This adult component could be used as an additional component to other HSI models.

A hypothetical model was developed from 1990 field observations in Maine and New Brunswick by assuming that pool habitat is unsuitable when temperatures exceed 28°C. This assumption is based on observations of Dennys River salmon leaving pools at 28°C to seek cold springs. Other model variables include depth, velocity, instream cover, and proximity to spawning habitat. The HSI is the arithmetic mean of the SI's for these variables.

Habitat data collected in 1991 from the Dungarvon and Big Salmon rivers in New Brunswick were used to create SI's and revise the hypothetical model. Salmon density was determined by snorkeling. Details of data analysis were not provided. The authors used data from each river in multiple or simple regressions to determine relations between habitat variables and salmon density in holding pools. Correlations among habitat variables were also conducted. Further analysis may have been done to determine significant differences in density depending on the values of a given habitat variable; however, the text is vague. For instance, the authors stated that there was a significant increase in mean salmon density in pools deeper than 0.9 m, but the method of analysis is unclear. Pool depth and proximity to spawning habitat were significantly related to salmon density. Optimal conditions included maximum pool depth >0.9 m, instream cover >20%, and spawning habitat within 0.8 km.

Presence of springs and nearby riffle habitats may influence pool suitability, but these characteristics were not included in the model. In addition, human influences, such as logging, roads, and angling pressure, may be relevant but were not included in the model. Salmon densities were much lower than historical densities; thus, many pools that previously held salmon were empty. Because the performance measure was salmon density, inclusion of empty, yet suitable, pools in the data base could cause the model to underestimate pool suitability. The authors thought that using the arithmetic mean for this model should minimize the possibility of suitable pools being classified as unsuitable.
Suggested revisions: The authors provided a model component for adults in holding pools that can be integrated with other models.

Reference: Trial, J. G., and J. G. Stanley. 1995. Habitat suitability index models: Nonmigratory freshwater life stages of Atlantic salmon. U.S. Department of the Interior, National Biological Service, Biological Science Report 3. 19 pp.
Synopsis: This report describes a new Atlantic salmon habitat model and reviews the literature on Atlantic salmon. Egg, embryo, fry, and parr life stages are considered; however, the model only applies to adults selecting spawning sites. The model may be applied to landlocked and anadromous populations in streams of New England and Canada.

This paper is refreshing in its detailed and candid presentation on the constraints, limitations, and assumptions necessary in developing and using an HSI model. For instance, the authors specify whether information for a given environmental variable was adequate or inadequate for developing an SI (e.g., they had insufficient information to develop SI's for fall or winter velocities). The intent of HSI models is to predict habitat quality in the absence of confounding factors such as contaminants, human harvest, or competition. Other aspects besides SI curves that are important in using the model include season, the need for unobstructed passage between habitats, and data collection methods.

Seventeen SI's for environmental variables are presented. The variables are from the original model (see first synopsis under Atlantic salmon); SI's have been modified to reflect information from later studies. The authors did not test the new model but summarized results from other studies that validated some of the SI's, especially those for water velocity, depth, and substrate for fry. Lifestage component indices were calculated as

the product of individual SI's; the water quality component was calculated using a minimum value approach.

Ideal and alternative methods for collecting the habitat data necessary to run the HSI model are described. The model is presented as an additional model for use in rating adult habitat.

Suggested revisions: Add the adult component to models of younger life stages.

Black Bullhead (Ameiurus melas)

Summarized by: Jeanette Carpenter

Reference: Gilbert, R. J. 1984. Assessments of selected habitat suitability index (HSI) models. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):275–390.

Synopsis: HSI's predicted by draft versions of published models were compared with standing stock of all bullheads (*Ameiurus* sp.) estimated by rotenone surveys in southeastern reservoirs and rivers. Reservoir data were obtained from several publications. Physical habitat data were collected at the time of the surveys; chemistry data were obtained from U.S. Geological Survey publications. Data for multiple years were averaged to derive habitat variables. Percent bottom cover, substrate, percent pools, water level fluctuation, and vegetative cover were estimated by biologists familiar with the sites. Models were evaluated by correlation; however, alpha levels were not chosen.

Black bullheads were not expected to occur in all six reservoirs. Most of the 16 draft SI's were developed from data on other bullheads and catfishes and assume habitat preferences of other species are appropriate for black bullheads. The standing stock data used to test the model did not clearly separate among bullhead species. Bullheads (all species) were caught in four of the six reservoirs. The correlation of black bullhead HSI with total bullhead standing stock was low ($r = 0.336$, $P = 0.515$).

The sampled rivers were not within the native range of black bullheads, and this species was not found. Removing SI variables that produced an HSI value of zero and testing using only brown bullhead (*A. nebulosus*) standing stocks resulted in low correlation with HSI for both the original ($r = 0.200$) and modified ($r = 0.263$) HSI model.

Problems with model testing included possible biases with cove rotenone samples. General problems with HSI models include dependence among variables, inadequate consideration of the ability of fish to find refuge from short-term adverse conditions such as high temperatures or fast water velocities, difficulty in obtaining precise information required by some variables, failure to consider interspecific interactions and angling pressure, the untested assumption that standing stock directly reflects carrying capacity, and the potential for model variables to not be limiting. There is not enough information on black bullhead habitat requirements to develop either a reservoir or riverine HSI model for this species.

Suggested revisions: None.

Black Crappie (Pomoxis nigromaculatus)

Summarized by: Jeanette Carpenter

Reference: Knights, B. C., and B. L. Johnson. 1994. Winter component for the riverine version of the habitat suitability index (HSI) model for black crappie, *Pomoxis nigromaculatus*. Unpublished report, U.S. Fish and Wildlife Service, National Fisheries Research Center, La Crosse, Wisconsin.

Synopsis: Lack of suitable winter habitat may limit black crappie in northern rivers. This study presents a winter component to add to FWS/OBS-82/10.6. Neither the original HSI model nor the new winter component model were tested with independent data.

The winter component is based on literature sources and earlier work by Knights and is the geometric mean of SI's for DO, water temperature, and current velocity in backwater systems that become ice covered. The winter component should be incorporated into the original model in a manner similar to the other components.

The modified HSI model is best applied in habitats with homogeneous DO, temperature, and velocity conditions; however, riverine backwater systems are typically diverse, and the three habitat variables often vary in these areas. Thus, the winter component may be limited by the requirement of habitat homogeneity.

Suggested revisions: Add the winter component to the riverine version of the original HSI model.

Reference: Gilbert, R. J. 1984. Assessments of selected habitat suitability index (HSI) models. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):275–390.

Synopsis: Data collection and analysis techniques and problems with model testing and HSI models in general are the same as described in the synopsis for this publication under black bullhead.

Black crappie were expected to occur in all of the sampled rivers and reservoirs, which were in the species' natural range. Black crappie were caught in four of the six reservoirs; HSI's were highly but negatively correlated with estimated standing stocks ($r = -0.74$,

$P = 0.093$). Reservoirs with the lowest HSI's contained the highest standing stock. Black crappie were caught in five of the six sampled rivers. There was no significant correlation between standing stock ranks and HSI.
Suggested revisions: The reservoir model should consider habitat characteristics of waters deeper than the littoral zone.

Blacknose Dace (Rhinichthys atratulus)

Summarized by: Jeanette Carpenter

Reference: Trial, J. G., C. S. Wade, and J. G. Stanley. 1984. HSI models for northeastern fishes. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):17–56.
Synopsis: A blacknose dace model developed from the literature was field tested by collecting habitat and standing stock data during low summer flow from 11 stream sections in Maine. Standard stocks were estimated by multiple removal or mark-recapture using electrofishing equipment. Values for habitat variables were converted to SI's using SI curves. The HSI's for each site were compared with standing stock estimates using nonparametric rank correlations. The ability of the model to detect presence or absence was also tested. All statistical tests used an alpha level of 0.20. Blacknose dace were found in 6 of the 11 stream sections. However, the model did not accurately predict blacknose dace presence or absence, and ranks of HSI's were not correlated with ranked standing stocks (probability of correlation = 0.60). Suitable spawning temperature had too narrow a range; thus, the reproductive component value was underestimated. The adult velocity curve may be unrealistic. The maximum temperature SI does not consider the ability of fish to find refugia.

Problems impeding development of HSI models include scarcity of data on variables that limit distribution and abundance, especially for species such as blacknose dace, which are not well studied. Observed values for habitat variables are often descriptive and not linked to a response variable such as standing stock, survival, growth, or reproduction. How individual SI's should be aggregated into a single HSI is unclear. Problems in using the HSI model include unexplained methods for measuring variables and the apparent need for extensive monitoring data.

Model variables should be less simplistic, with more detailed explanations of how field data should be managed. The model has variables that are interrelated. Several variables are difficult to obtain, such as annual minimum pH.

Suggested revisions: None.

Reference: Trial, J. G. 1989. Testing habitat models for blacknose dace and Atlantic salmon. Ph.D. dissertation, University of Maine, Orono. 128 pp.
Synopsis: Trial's test consisted of four phases: evaluating the published HSI model for internal logic, comparing predicted SI distributions with empirical distributions using joint probabilities and geometric means, revising the model based on the first two tests, and testing the revised and published models with independent data by correlating rankings and population densities.

The overall subjective evaluation of model logic was developed by classifying each variable as a limiting, controlling, masking, directive, or lethal factor and analyzing fundamental biological and mathematical relationships. For some variables, such as temperature, classification can change. Suitability indices for depth, velocity, and substrate were tested by comparing the distribution of individual fish with the distribution of the points on the SI curves. Suitability indices for stream width, percent shade, and percent pool were evaluated with fish density data. Component indices were tested by comparing the distribution of individual fish with the distribution of component index (CI) values. The HSI was tested by comparing it to average population over a 10-year period. Data analysis techniques were similar to those described for this reference under Atlantic salmon.
Suggested revisions: Based on overall test results, Trial recommended revising the definitions of seven model variables, changing the suitability index graphs for two variables, and eliminating variables for stream width, percent pools, percent shade, and gradient from the model. Eliminating the variables led to elimination of the food and cover component. Trial presented a new model based on five components (reproduction, adult, juvenile, fry, water quality).

Bluegill (Lepomis macrochirus)

Summarized by: Jeanette Carpenter

Reference: Nelson, D. A., and A. C. Miller. 1984. Application of Habitat Suitability Index models for white crappie, bluegill, and largemouth bass. Proceedings of a workshop on fish habitat suitability index models. U.S. Fish and Wildlife Service Biological Report 85(6):251–274.

Synopsis: The authors' objectives were to test and modify the model using rotenone samples of enclosed areas in 25 borrow pits along the Mississippi River. They wanted to verify the model and determine steps required to apply

it to a specific habitat. They analyzed the data by alternately testing hypotheses, making model modifications, and testing the results.

Borrow pit data were used to test 13 variables from the lacustrine version of the bluegill HSI model. Bluegill standing stocks had a low correlation ($r = 0.09$, $P = 0.40$) with HSI. Possible reasons for low correlation included fishing pressure, competition, farming and grazing practices, and spring flooding. A critical problem with the model was that littoral water temperatures (V10) >30°C have an SI of zero while borrow pits with viable bluegill populations had littoral zone temperatures from 28° to 34°C. The authors used principal components analysis to group fish according to 13 habitat variables and to identify variables related to dissolved solids, maximum DO, substrate composition, and temperature for exclusion from HSI models.

A new variable, SI for percentage of water >1.5 m deep, was added because most borrow pits <1.0 m deep dried out by fall. The remaining original variables and the new variable were used to obtain a second set of HSI values which correlated with observed standing stocks ($r = 0.46$, $P = 0.025$) better than the original HSI's. Standing stocks and the modified HSI values were compared using principal components analysis. Variables related to cover had high loading, and another model version (Modification II) included the four cover variables (percent of snags, aquatic vegetation, littoral area, and deep water). These data had a slight correlation ($r = 0.48$, $P < 0.01$), yet one extreme data point may have influenced this analysis. The authors also tested Additional Model 2 in FWS/OBS-82/10.8. This model was not well correlated with observed standing stocks ($r = 0.11$, $P = 0.2$).

Suggested revisions: Add a variable for percent water >1.5 m deep and remove several original variables.

Reference: Gilbert, R. J. 1984. Assessments of selected habitat suitability index (HSI) models. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):275–390.

Synopsis: Data collection and analysis techniques and problems related to testing and developing HSI models were the same as described in the synopsis for this publication under black bullhead.

The six reservoirs were expected to support bluegill populations. The models were tested for their ability to estimate standing stocks in coves, not the entire reservoir. Gilbert noted that bluegill HSI values were fairly highly correlated with estimated standing stocks ($r = 0.498$); however, the probability level ($P = 0.315$) was not significant. Gilbert stated that the correlation may have been high because some of the variables allowed more flexibility in determination of their values. For instance, DO in summer (V7) has categories such as "seldom" and "usually," which allows the user to ignore short-term events. No modifications were attempted with the reservoir model.

All river sites were expected to contain bluegill. Bluegill HSI values were highly correlated with estimated standing stocks ($r = 0.79$); this correlation was moderately significant ($P = 0.059$).

Suggested revisions: None.

Reference: Knights, B. C., and B. L. Johnson. 1993. Winter component for the riverine version of the habitat suitability index (HSI) model for bluegill (*Lepomis macrochirus*). Unpublished report, U.S. Fish and Wildlife Service, National Fisheries Research Center, LaCrosse, Wisconsin.

Synopsis: Knights and Johnson did not directly evaluate the riverine version of the model but provided a winter component for ice-covered backwater areas to be added to the model. One-third of the bluegill range is in northern regions; a winter component should expand the model's applicability.

The authors provided a brief, general description of Knight's study of radio-tagged bluegills in ice-covered backwater lakes of the Upper Mississippi River to determine winter habitat in relation to spatial and temporal gradients of DO, water temperature, and velocity. (Information from this study was subsequently published in North American Journal of Fisheries Management 15:390–399.) In winter, bluegill preferred areas with velocity <1 cm/s, temperature >1°C, and DO >3 mg/L. When DO was <3 mg/L, bluegill usually sought areas with greater velocity and colder temperatures, especially after ice formation.

The authors developed winter SI's for ice-covered backwater systems from Knights' data and literature on bluegill or other fishes. The suggested winter component is made up of three variables: minimum DO concentration, water temperature, and current velocity. The winter component index is the geometric mean of the SI's for these variables and would be the sixth component in an HSI model.

The new component is best applied if habitats exhibit homogeneous conditions for the three habitat variables, which may limit the value of the HSI model. They did not test the winter component model, or a new HSI model containing the component, with independent data.

Suggested revisions: Add the winter component for ice-covered backwater areas to the original HSI model.

Brook Trout (Salvelinus fontinalis)

Summarized by: Jeanette Carpenter

Reference: Schmitt, C. J, A. D. Lemly, and P. V. Winger. 1993. Habitat suitability index model for brook trout in streams of the Southern Blue Ridge Province: Surrogate variables, model evaluation, and suggested improvements. U.S. Fish and Wildlife Service Biological Report 18, Washington, D.C. 43 pp.

Synopsis: Values for published model variables are difficult to obtain without intensive sampling (e.g., V2 is average maximum temperature during embryo development). The authors' objective was to correlate original variables with more easily obtainable ones, which could be used as surrogate variables so that the model would be more useful. Surrogates tested were stream width, order, gradient, elevation, and pH. The authors also evaluated the overall applicability of the published model for the study area.

The analysis was conducted with four sets of data used separately and in combinations. Regression and correlation analysis determined if surrogate variables predicted original variables. For the two sets of data describing fish densities, they used separate regression analyses to quantify variable-standing stock relations in streams with only brook trout and streams that included other fishes. Fish were sampled with single-pass electrofishing. Forward-selection, stepwise multiple regression was used to fit the models. Variables were added if the addition resulted in a significant ($P < 0.05$) reduction in unexplained sum-of-squares. They did other regression analyses to determine specific relations within the sets of data.

Three of the four sets of data were combined for cross-validation analyses, which produced equivocal results. Problems occurred using least squares regression-correlation analysis to determine relations between habitat variables, predict trout density, and conduct cross-validation studies. Trends in habitat with elevation were consistent among the sets of data. Rainbow trout are key competitors in the system, and variables related to invertebrate abundance may not be limiting factors for brook trout. In rainbow trout streams, pH and measurements from maps or aerial photographs can be used to a limited extent for predicting brook trout habitat quality. Gradient, pH, elevation, width, and rainbow trout density were more precise at explaining brook trout abundance than the HSI model. Limitations and assumptions of the regression-correlation approach were compared with principal components analysis.

Suggested revisions: The model may be biased towards regions where warm-season habitat is limiting. Inclusion of a variable describing availability of feeding locations would be useful to assess potential foraging competition in streams with rainbow trout. The water quality component should be revised to reflect recent information on pH and related variables.

Brown Trout (Salmo trutta)

Summarized by: Jeanette Carpenter

Reference: Wesche, T. A., C. M. Goertler, and W. A. Hubert. 1987. Modified habitat suitability index model for brown trout in southeastern Wyoming. North American Journal of Fisheries Management 7:232–237.

Synopsis: The authors tested the HSI model with biomass and habitat data from 30 sites on nine streams in southeastern Wyoming. At 27 sites, fish were sampled with electrofishing gear and numbers estimated with the DeLury removal method. Populations at the other three sites were sampled with sodium cyanide. Thirteen of the 18 HSI model variables were measured. Unmeasured variables were related to spawning and water quality. Because the populations were reproducing naturally and water quality was excellent, they assumed that model performance would not be impacted if unmeasured variables were given an optimal rating of 1.0. They collected data on 25 additional habitat variables and used simple linear regression to determine the relation between each independent habitat variable and brown trout biomass. Variables with significant correlations were used to develop multiple regression models to predict biomass.

The HSI model failed to explain variations in brown trout standing stock, although the water quality component was significant but weakly correlated ($R^2 = 0.18$). Recalibrating the SI's with the Wyoming data did not improve model performance. Two of the original SI graphs produced ratings that were significantly related to standing stock: The variables were average annual base flow as a percent of average annual daily flow (V14; $r^2 = 0.36$) and percent of stream area shaded (V17; $r^2 = 0.24$). Seven other habitat variables exhibited significant but weak correlations ($r^2 \leq 0.29$). The authors used these nine habitat variables to develop a multiple regression model. The best model used a modified trout cover rating (MTCR) and variable V14 ($R^2 = 0.52$; $P = 0.003$): standing stock (kg/ha) = 0.71 * MTCR + 114.3 * V14 - 0.60. The MTCR variable by itself was a weak predictor ($r^2 = 0.18$).

Simple linear regression indicated that fishing pressure was a significant but weak predictor of standing stock ($r^2 = 0.16$). Cover and base flow regime are universally important to brown trout, and the revised model should be applicable to other regions, especially if

base flow regimes are altered. The revised model was developed from the data presented in the paper and was not tested.

Suggested revisions: Specific revisions to the published HSI model were not described. The modified model is an alternative.

Reference: Heggenes, J. 1988. Physical habitat selection by brown trout (*Salmo trutta*) in riverine systems. Nordic Journal of Freshwater Research 64:74–90.

Synopsis: Results from several studies were analyzed to determine why brown trout habitat selection varies. The author compared the model in Biological Report 82(10.124) to other brown trout models and habitat studies and evaluated the assumption of habitat variables independently affecting habitat selection, inherent biases in observation methods, varying techniques in collecting substrate and cover data, influence of behavior (e.g., intra- and inter-specific competition), effect of fish size on habitat selection, and ranking of habitat variables.

Suggested revisions: None. However, developing SI's on site instead of transferring to another stream and quantifying habitat availability data because of its influence on habitat choice was recommended.

Reference: Beard, T. D., Jr., and R. F. Carline. 1991. Influence of spawning and other stream habitat features on spatial variability of wild brown trout. Transactions of the American Fisheries Society 120:711–722.

Synopsis: Number of fish per surface area was determined by electroshocking and mark-recapture or removal methods in 12 reaches of an unharvested, unstocked creek in central Pennsylvania. Redd densities and distribution and embryo survival were also measured. Each habitat measurement included in the HSI model was assigned an SI value; variables common to all sections were not used. The HSI for a reach was determined by the mean of individual SI's.

Mean HSI and brown trout densities were poorly correlated (Spearman rho = –0.30 for juveniles and –0.23 for adults). Most correlations of habitat measurements (such as depth, pool area, cover, and substrate) with densities of juvenile and adult brown trout were negative. In addition, no correlations were found between redd distributions and spawning habitat HSI.

Neither direct measurements of habitat features nor the HSI explained variation in brown trout densities. The SI's need to be more carefully defined to allow accurate assessment of spawning habitat. Poor correlation between density and HSI may be the result of recruitment—not habitat features—limiting the brown trout population. Juveniles do not disperse widely from natal areas, and thus local fish densities are more a function of the availability of spawning habitat.

Suggested revisions: Including a measure of substrate embeddedness would improve the spawning habitat rating (embryo lifestage).

Channel Catfish (Ictalurus punctatus)

Summarized by: Jeanette Carpenter

Reference: Zaroban, D. W. 1987. A field test of habitat evaluation procedures for creek chub (*Semotilus atromaculatus*) and channel catfish (*Ictalurus punctatus*). M.S. thesis, University of Nebraska, Lincoln.

Synopsis: Zaroban tested the riverine model by comparing HSI values with population and biomass estimates at 16 stream sites in the Elkhorn River basin in Nebraska. Sites were selected by a stratified random design. Habitat and biomass data were obtained in separate trips. Channel catfish were caught with electrofishing gear, and population numbers were estimated using a removal method.

The six sites that contained channel catfish had an HSI greater than zero. Two of the 16 sites yielded population, biomass, and HSI values of zero. Eight sites had no channel catfish yet yielded HSI values greater than zero. Using data from all 16 sites, Zaroban found weak yet highly significant correlations of HSI to population and biomass (Kendall's tau = 0.500; $P = 0.008$).

When only the six sites where channel catfish occurred were analyzed, the data fit the model. Kendall's correlation test yielded coefficients of 0.714 for both comparisons (no P-values were given).

According to the HSI model in FWS/OBS-82/10.2, the lower limit for average water temperatures in pools, backwaters, and littoral areas during spawning and embryo development is 15°C. Arbitrarily increasing the lower limit to 17°C improved the correlation of the data for the sites without channel catfish; however, Zaroban did not recommend changing the model. Channel catfish were collected at an insufficient number of sites to provide an adequate test of the model. More complete temperature monitoring to develop SI's for Nebraska was suggested, since the limiting variables were all temperature variables.

Because the absence of a species at a site can be attributed to a wide variety of causes other than habitat quality, it is not necessarily appropriate to include sites without the target species in the model test. However, the sites with the lowest HSI values (HSI ≤ 0.1), and thus the poorest predicted habitat quality, did not contain channel catfish. Also, Zaroban's HSI values at the six sites with channel catfish correlated with the biomass and population estimates. These features of his study support the published model.

Suggested revisions: None.

Reference: Layher, W. G., and O. E. Maughan. 1985. Relations between habitat variables and channel catfish populations in prairie streams. Transactions of the American Fisheries Society 114:771–781.

Synopsis: Layher and Maughan developed and tested SI's for channel catfish from data collected at 209 stream sites in Kansas by graphing estimated standing stocks (kg/ha) of channel catfish against 19 abiotic variables. Standing stock data were collected using eight different sampling methods. To develop a predictive model relating fish biomass to SI values of habitat variables, the authors used data from 42 sites sampled by mark and recapture, with a final recapture using rotenone. Stepwise multiple regression analysis resulted in the following model ($R^2 = 0.50$; $P < 0.01$): standing stock (in kg/ha) = -275.13 + (126.60 x maximum width SI) + (178.76 x runoff SI) + (179.90 x percent run SI) + (223.58 x water temperature SI).

The authors compared standing stocks predicted by the Kansas regression model with biomass estimates obtained by depletion methods using electroshocking gear in 23 Oklahoma streams. The Pearson correlation between Oklahoma standing stocks and standing stocks predicted by the Kansas equation was highly significant ($r = 0.52$; $P < 0.01$). I believe that significance is due to a single outlier (see Fig. 2 in Layher and Maughan's publication); however, this was not discussed by the authors. To produce a separate Oklahoma model, the suitability index graphs developed from the Kansas data were used to rate Oklahoma habitat. Stepwise regression resulted in a univariate model ($r^2 = 0.48$; $P < 0.01$): standing stock (in kg/ha) = -2245.47 + (3200.30 x percent riffle SI).

The two models are very different from each other. Abiotic variables significant in the Kansas model did not explain variation in Oklahoma data, and vice versa; there are numerous explanations for this occurrence. The simplest explanation is that variables limiting channel catfish differ between the two states. However, other potential explanations for the lack of consistency between the two regions include the following: data collection techniques between regions differed; the assumption that SI's developed in Kansas can be applied to Oklahoma streams may be incorrect; variables not included in the regression model may limit populations at a site; assumptions of linear regression were not met for these models (e.g., data may have been heteroscedastic and nonnormal); and correlations were weak for the models, indicating their low power to predict standing stocks.

The authors did not provide biological reasons for why channel catfish populations might respond only to such variables as maximum width, runoff, percent run and riffle, and water temperature. However, they did note that because channel catfish are a species that occupies a broad niche, abiotic variables may provide minimal explanation for standing stock variation among sites.

The SI's for water temperature, turbidity, and DO developed in this study closely resembled the published SI's. The authors suggested that these three SI's adequately describe habitat suitability for a single variable.

Suggested revisions: None. Regression models are presented as an alternative.

Reference: Layher, W. G., and O. E. Maughan. 1984. Analysis and refinement of habitat suitability index models for eight warmwater fish species. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):182–250.

Synopsis: The same data and results described for this study are also presented in Layher (1983). This study used draft suitability indices available prior to model publication and the same data used in the study described in the previous synopsis. Using Kansas data, the authors tested a geometric mean model based on draft SI's, developed and analyzed a presence-absence model, obtained SI's for 19 variables, and provided biomass models using stepwise regression analysis for eight different fish collection methods. They also tested the presence-absence model and biomass model with Oklahoma data.

Mean values of eight habitat variables were significantly different (t-tests) at sites where channel catfish were present compared with sites where they were absent. The presence-absence model correctly classified 88% of the sites where channel catfish were absent; however, only 40% of sites where channel catfish were present were classified correctly. They used a discriminatory procedure to classify each stream site in Oklahoma to determine if channel catfish presence or absence could be predicted, and they also developed a presence-absence model based on Oklahoma data. The accuracy of the Kansas model was reduced when applied to the Oklahoma data, and the Oklahoma model was the best predictor of presence or absence of channel catfish. Oklahoma data were probably more reliable because they were collected with one field crew and one fish capture method.

In general, the individual SI's developed from the Kansas data were very similar to the draft SI's, which were developed from literature reviews. The authors suggested that this similarity supports the approach used to develop the draft SI's.

Standing stock estimates varied depending on the type of capture method used. When all Kansas data were used, there were no significant relations between standing stocks of individual species and SI values for abiotic

variables. However, when each capture method was analyzed separately, seven of the eight capture methods yielded significant stepwise regression models. Each regression model contained different combinations of abiotic variables.

Researchers are more likely to be able to develop an accurate habitat suitability model for species with narrower environmental tolerances than channel catfish. Reliable models may only be built over small, homogeneous geographical areas; researchers may need to address synergistic effects of variables; and there is no clear method to develop numerical models for aggregating SI's into an HSI.

Suggested revisions: None. Alternative models were provided.

Reference: Gilbert, R. J. 1984. Assessments of selected habitat suitability index (HSI) models. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):275–390.

Synopsis: Data collection and analysis techniques and problems with developing and testing HSI models are the same as described in the synopsis for this publication under black bullhead.

The six reservoirs and six rivers sampled were expected to support channel catfish, even though they are not native to the study area. Reservoir HSI's were not well correlated with estimated standing stocks ($r = 0.461$, $P = 0.366$). The author thought fishing pressure, not habitat, was limiting channel catfish populations in reservoirs, although no evidence was provided.

Riverine HSI values were poorly correlated with estimated standing stocks ($r = 0.049$, $P = 0.927$). Although standing stocks varied among sites, HSI did not. All of the sampled rivers sustain commercial catfish fisheries; thus, as mentioned for the reservoir model, fishing pressure may be limiting populations.

Suggested revisions: None.

Chinook Salmon (Oncorhynchus tshawytscha)

Summarized by: Jeanette Carpenter

Reference: Weigand, D. C. 1990. Evaluation of the juvenile component of the chinook salmon habitat suitability index (HSI) model. Unpublished report, Seattle National Fisheries Research Center, Washington.

Synopsis: Data were originally collected for other studies; some variable values were approximated from additional data sources. The juvenile component of the HSI model was tested with data collected in 20 streams in Idaho over a 3-year period. Temperature, habitat availability, and habitat parameters (e.g., depth, dominant substrate type, instream and bank cover status, percent embeddedness) were measured. Snorkelers determined densities of age-0 chinook salmon by counting fish in representative plots. Drainage, year, and summer period defined four groups of density estimates. Density within groups determined observed SI values.

Weigand used three criteria to evaluate fit of observed SI values with the published SI curves: percent of observed SI's that fell above the curve, distance between the curve and observed SI's above the curve; and range of SI's. Five variables that were approximated were ill fitting: pH (V1), DO (V3), relative mean annual base flow (V11) and peak flow (V12), and nitrate-nitrogen levels (V15). These SI's were not revised. Observed SI's that fit published SI's were variables that were collected consistently: maximum temperature (V2), percent of pools (V4), bank cover (V16B), and boulders (V17). Observed SI's did not fit SI's for pool class rating (V5) and substrate rating (V13), possibly due to lack of clear definitions. Percent fines (V14) was ill fitting owing to poor estimates.

Weigand compared correlations between component SI's (for embryo, juvenile, and adult life stages) and observed SI's using various mathematical formulae. Component SI's derived from revised SI's correlated best with the observed SI's. The limiting factor approach is dangerous because model output is dictated by the value of a single input variable; variable aggregation approaches are safer. Point-in-time density estimates are unreliable indicators of habitat quality; thus, these types of estimates should not be used to test HSI models unless there are data for several years.

Suggested revisions: Based on the field data, Weigand made minor revisions to V2 such that an SI of 1.0 occurs for temperatures of 12° to 19°C and then decreases to an SI of 0.4 at 25°C. He divided V16 into V16I (for instream cover) and V16B (for bank cover). The SI for V16I was revised to increase linearly from zero at zero cover to 1.0 at 10% cover. The SI for V17 (percent boulders) was revised to increase linearly from zero at zero boulders to 1.0 at 10% boulders. Definitions of pool and substrate class ratings should be less ambiguous. Input variables based on basin characteristics and biological factor variables should be included to improve model performance.

Chum Salmon (Oncorhynchus keta)

Summarized by: Jeanette Carpenter

Reference: McMahon, T. E. 1987. Assessment of the habitat evaluation procedures (HEP) approach to

measuring environmental impacts: Testing the coho and chum salmon Habitat Suitability Index (HSI) models with Carnation Creek data. Unpublished report, National Ecology Research Center.

Synopsis: McMahon evaluated the ability of the chum salmon model to predict the degree and direction of changes in habitat and fish populations due to logging activities. Habitat and fish data were collected at nine sites before, during, and after logging from Carnation Creek, British Columbia. This paper is unusual in that it evaluates an HSI model using 15 years of monitoring data collected for other studies. Chum salmon use Carnation Creek for spawning and embryo incubation. Study objectives were to compare HSI's before and after logging and to test the relation of carrying capacity to HSI's and individual SI's by correlating with population data. McMahon provided detailed descriptions of how data were collected, how measurements were estimated from other data, and why some SI variables were omitted.

Habitat data were converted to SI values using published SI curves. Component indices and HSI's were obtained by aggregating SI's using interactive limiting factor, limiting factor, and average value methods. Population data included percent egg-to-fry survival, fry numbers, and adult recruitment. Fish were sampled with a fish counting fence and by intensive pole seining and electroshocking. Model accuracy was evaluated by subjectively comparing model behavior with known habitat changes and by using rank correlation analysis to compare population parameters with model outputs.

In pre-logging years, HSI's and population measurements (fall population numbers and densities, smolt output, and adult returns) were relatively stable; limiting variables were substrate composition and intragravel DO and temperature. After logging, HSI's and HU's declined by 60% (the limiting variable was primarily intragravel DO), egg-to-fry survival declined by 49%, and fry numbers declined by 85%. The HSI's accurately represented gravel quality declines. Adult recruitment was significantly correlated with HSI's calculated with all three aggregation methods. Individual SI's were evaluated by rank correlation, by plotting fish data directly on SI curves, and by comparing magnitude and direction of SI changes with observed magnitude and direction of habitat changes. The limiting factor aggregation method reflected limiting conditions and was more sensitive to population declines after logging. There was no significant correlation between individual SI's and egg-to-fry survival.

The chum salmon HSI model provided good measures of the magnitude and direction of habitat changes and fish population responses. Long-term comprehensive data and understanding of processes are invaluable for evaluating habitat models; point-in-time data do not allow researchers to pinpoint causes of model failure (or success) or account for lags in population responses. Correlation statistics alone are insufficient to determine habitat model validity. If possible, a habitat model should be evaluated with several population parameters instead of one.

Suggested revisions: Adjust temperature curves to represent regional differences.

Coho Salmon (Oncorhynchus kisutch)

Summarized by: Jeanette Carpenter

Reference: Li, H. W., C. B. Schreck, and K. J. Rodnick. 1984. Assessment of habitat quality models for cutthroat trout *(Salmo clarki clarki)* and coho salmon *(Oncorhynchus kisutch)* for Oregon's coastal streams. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):16–57.

Synopsis: The authors evaluated whether interspecific competition from coho salmon and steelhead trout changed cutthroat trout habitat suitability, tested empirically derived SI's with SI's from an independent set of data, and compared HSI's calculated from three approaches with those derived by dividing observed standing crops by maximum standing crops. Primary emphasis was on cutthroat trout. The study used data of other researchers working in the Smith and South Coos drainages, as well as the data from the Nestucca drainage that is described in the cutthroat trout synopsis. Populations in all streams were estimated by removal techniques.

The tested SI's were from a draft model and not at all similar to the SI's found in FWS/OBS-82/10.49. Draft SI's included velocity, percent pools and riffles, depth, DO, temperature, and pool volume. These graphs were used to define SI's to compare with the Nestucca data using the approach of dividing by maximum standing crop. Apparently, only the predicted pool volume SI was compared with Nestucca standing stock data. Neither statistical comparisons nor sample sizes were included; nevertheless, there was a lack of correlation between predicted and observed SI's.

Three SI aggregation approaches were evaluated: The average value method, interactive limiting factor method, and lowest suitability index approach. HSI's from the three aggregation approaches did not accurately predict HSI's derived by dividing by maximum standing crop. Percentages of correct classifications for the three approaches changed when biotic variables were left out. Validation tests for coho salmon showed low correlations

between predicted and observed HSI's. Low correlations may have been caused by differences in measuring or defining variables, by not including key variables, or by differences in data collection methods between studies. The assumption that dividing observed standing crop by maximum standing crop was the best approach for defining observed HSI was not addressed.

Stepwise discriminant analysis of the coho salmon data from the Nestucca drainage resulted in stream reaches consistently assigned to the correct group (percent of correct classifications ranged from 83% to 91%). The most important discriminating factors varied among the two creeks. Stepwise discriminant analysis was more accurate than the other three approaches.

Suggested revisions: None.

Reference: McMahon, T. E. 1987. Assessment of the habitat evaluation procedures (HEP) approach to measuring environmental impacts: Testing the coho and chum salmon habitat suitability index (HSI) models with Carnation Creek data. Unpublished report.

Synopsis: McMahon evaluated the ability of the coho salmon HSI model to predict the degree and direction of change in habitat and fish populations from logging activities. Habitat and fish data were collected at nine sites before, during, and after logging from Carnation Creek, British Columbia. This paper is unusual in that it evaluates an HSI model using 15 years of data. Study objectives were to compare HSI's before and after logging and to test the relation between carrying capacity and HSI's, component indices, and individual SI's by correlating with population data. Detailed descriptions of data collection and analysis techniques and explanations of why some SI variables were omitted are provided.

Habitat data were converted to SI's using published SI curves. Component indices and HSI's were obtained using the interactive limiting factor and average value methods described in the synopsis for this paper under chum salmon. Numbers of spawners, young fish within the stream, and coho smolts migrating to sea were sampled with a fish counting fence, intensive pole seining, and electroshocking. Model accuracy was evaluated by subjectively comparing model behavior with known habitat changes and by using rank correlation analysis to compare population parameters with model outputs for prelogging and postlogging years. In prelogging years, HSI's and population measurements were relatively stable. After logging, HSI's and HU's declined by 30%, and all population parameters (except smolts) dropped by about 30%.

Due to complex interactions between habitat and population response, prelogging and postlogging years were analyzed separately, and logging years were omitted. Fall numbers and densities were significantly correlated with HSI's (r from 0.66 to 0.72). Analysis of food and water quality component indices produced similar results. Individual SI's were evaluated by rank correlation, by plotting fish data on SI curves, and by comparing magnitude and direction of SI changes with observed magnitude and direction of habitat changes. Egg-to-fry survival was significantly correlated with SI's for intragravel temperature (negative correlation), substrate, and percent fines; fall density was correlated with summer temperatures, percent canopy, canopy composition, and pool quality.

Calculation of HSI's by the average value method resulted in a much less significant decline in mean HSI's than use of the interactive limiting factor method. HSI's among logging treatments were also compared. Changes in many individual SI's appeared to correspond with known habitat changes. The SI's did not reflect pool location shifts in postlogging years. SI's for winter cover and temperature did not accurately represent declining habitat conditions after logging. Coho have been able to compensate for short-term habitat changes. McMahon's conclusion about evaluating the coho salmon model were the same as those he described for coho salmon in this same paper.

Suggested revisions: Include more detailed data on winter habitat requirements, and adjust temperature SI's to be more regionally representative.

Common Carp (Cyprinus carpio)

Summarized by: Jeanette Carpenter

Reference: Gilbert, R. J. 1984. Assessments of selected habitat suitability index (HSI) models. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):275–390.

Synopsis: Data collection and analysis techniques and problems with developing and testing this model are the same as described in the synopsis for the publication under black bullhead.

The six reservoirs and six rivers sampled in this study were expected to support common carp populations. Common carp HSI's from a draft reservoir model were moderately correlated with estimated standing crops ($r = 0.552$), but the author did not mention that significance was very low by most standards ($P = 0.256$). Reservoirs with very low or zero HSI values supported substantial carp populations.

Common carp were captured in four of the six sampled rivers. HSI values from the riverine model were poorly correlated with estimated standing stocks ($r = 0.117$, $P = 0.825$). Although standing stocks varied

among sites (0 to 136 kg/ha), HSI values had a fairly narrow range, between 0.49 and 0.62.
Suggested revisions: None.

Common Shiner (Notropis cornutus)

Summarized by: Jeanette Carpenter

Reference: Hubert, W. A., and F. J. Rahel. 1989. Relations of physical habitat to abundance of four nongame fishes in high-plains streams: A test of habitat suitability index models. North American Journal of Fisheries Management 9:332–340.
Synopsis: Forty-four habitat variables were measured at 29 stream sites in Horse Creek drainage, Wyoming. Study objectives were to correlate SI ratings for individual habitat variables with common shiner biomass, to produce HSI scores, and to develop multiple regression models to explain variation in biomass in relation to habitat variables. Biomass was estimated by using electroshocking data in the computer program CAPTURE. Six of the nine habitat variables used in the published model were measured; unmeasured variables were assigned an SI of 1.0.

Common shiners were found in eight sites. None of the habitat variables was positively correlated with biomass; two were negatively correlated: maximum summer temperature (r = -0.33, P = 0.002) and percent pools (r = -0.24, P = 0.025). The resulting HSI's were not related to biomass (r = 0.00, P = 0.996). Possible reasons for model failure include different limiting factors in separate geographical areas and lack of initial testing of SI and HSI values with fish biomass estimates. Assignment of an SI of 1.0 to the 10 missing variables in developing the HSI scores was not discussed as a possible reason for model failure.

Five habitat variables were correlated (positive and negative) with common shiner biomass. Habitat variables were selected for stepwise multiple regression analysis if they were correlated with standing stock but not with each other. New regression models were not tested. The observed relations between common shiner abundance and two of the habitat variables (submerged aquatic vegetation and silt substrate) are not supported by previous research. This difference may be due to small sample size. Habitat variables shown to be important to common shiners by other investigators are described.
Suggested revisions: None. Regression models are offered as an alternative.

Creek Chub (Semotilus atromaculatus)

Summarized by: Jeanette Carpenter

Reference: Zaroban, D. W. 1987. A field test of habitat evaluation procedures for creek chub (*Semotilus atromaculatus*) and channel catfish (*Ictalurus punctatus*). M.S. thesis, University of Nebraska, Lincoln. 45 pp.
Synopsis: Zaroban tested the riverine model with population and biomass estimates from 16 stream sites in the Elkhorn River basin in Nebraska. Sites were selected by a stratified random design. Habitat and biomass data were obtained in separate trips. Creek chub were caught with electrofishing gear, and population numbers were estimated using a removal method.

Of the 16 study sites, three sites yielded population, biomass, and HSI values of zero; three had HSI, population, and biomass estimates greater than zero; three had no creek chub but yielded HSI values greater than zero; and seven contained creek chub but had HSI estimates of zero. Zaroban used all 16 sites for comparing HSI values with the population and biomass data. Comparisons of HSI values to biomass estimates were weakly correlated yet highly significant for population and biomass (Kendall's tau = 0.541, P = 0.005, significance level indicates probability of observing the degree of correlation measured if the variables are independent). Zaroban's null hypothesis was that correlations between HSI and creek chub population and biomass estimates would yield correlation coefficients $\leq$0.8. Because the Kendall's tau was <0.8, Zaroban determined that his data do not support the published HSI model.

As published, variable V7 yields an SI of zero if turbidities are 150 nephelometric turbidity units or greater. Creek chub may be able to tolerate higher turbidities. Maximum summer temperature and spawning substrate SI's may be too restrictive and require further study.
Suggested revisions: Raise the turbidity levels that rate an SI of zero. Loosen restrictions on SI's for maximum summer temperature and spawning substrate.

Reference: Hubert, W. A., and F. J. Rahel. 1989. Relations of physical habitat to abundance of four nongame fishes in high-plains streams: A test of habitat suitability index models. North American Journal of Fisheries Management 9:332–340.
Synopsis: Data collection and analysis techniques are as described for this study for common shiner.

Hubert and Rahel tested 10 of the 20 habitat variables used in the model. Only percent pools during average summer flow (V1) showed a positive correlation with standing stock (r = 0.23; P = 0.028). To determine HSI, the authors assigned an SI of 1.0 to the 10 variables that they did not measure. The resulting HSI's were not related to biomass (r^2 = 0.003, P = 0.644). Possible reasons for model failure include different limiting factors in separate geographical areas and lack of testing of original SI and

HSI models with fish biomass measurements. The authors did not evaluate the assignment of an SI of 1.0 to the 10 missing HSI model variables as a possible reason for model failure.

Based on regression analysis, 4 of the 44 habitat variables exhibited weak ($r^2 < 0.3$) but significant ($P < 0.05$) correlations with creek chub biomass: mean current velocity (negative correlation), coefficient of variation of current velocity, percent of submerged vegetation, and percent of main-channel pool habitat. Stepwise multiple regression analysis yielded a single multivariate model ($R^2 = 0.55$, $P \leq 0.001$): standing stock (g/m^2) = 0.11 + (0.036 x percent submerged vegetation) + (1.351 x coefficient of variation of current velocity). The authors did not test their regression models. However, they provide biologically based arguments and literature citations explaining why creek chub biomass could be related to the four habitat variables.

Suggested revisions: None. Regression models are presented as alternatives.

Cutthroat Trout (Oncorhynchus clarki)

Summarized by: Jeanette Carpenter

Reference: Li, H. W., C. B. Schreck, R. A. Tubb, K. Rodnick, M. Alhgren, and A. Crook. 1983. The impact of small-scale dams on fishes of the Willamette River, Oregon, and an evaluation of fish habitat models. Water Resources Research Institute, Oregon State University, Corvallis. 81 pp.

Synopsis: The authors tested the assumption that only physiological responses are necessary to predict habitat use by examining the effect of competition with steelhead trout and juvenile coho salmon on cutthroat trout habitat use in two tributaries of the Nestucca River (Elk and Bear creeks). In these tributaries, natural barriers resulted in downstream sites containing all three species, while upstream sites contained combinations of the cutthroat trout with one of the other species. The authors determined SI's by dividing site standing stocks by the largest site standing stock of the reach. This approach yields at least one site per reach with an SI of 1.0. Suitability profiles were developed that related SI's to physical gradients. Variation among profiles at sites with and without sympatric populations was used to determine if competition caused a change in habitat use. To detect this variation, the authors used canonical correlation analysis and developed two habitat classifications, one based on relations between cutthroat SI values and physical variables and one based on combined physical and biological characteristics, such as densities of competitors.

Considering competitor densities increased habitat model accuracy. Competition appeared to be more intense in the creek disturbed by logging. However, another difference between the two creeks is that cutthroat trout above the barriers were sympatric with different species. The observed statistical patterns are not necessarily proof of competition, although other evidence supports the assumption of competition among these species. Modeling habitat without considering biological factors may be inadequate. Competition may mask a species' response to environmental gradients.

Suggested revisions: Biological factors should be considered in HSI models.

Reference: Li, H. W., C. B. Schreck, and K. J. Rodnick. 1984. Assessment of habitat quality models for cutthroat trout (*Salmo clarki clarki*) and coho salmon (*Oncorhynchus kisutch*) for Oregon's coastal streams. Proceedings of a workshop on fish habitat suitability index models. U.S. Fish and Wildlife Service Biological Report 85(6):57–111.

Synopsis: This study had several objectives: test the hypothesis that interspecific competition is an unimportant factor in determining habitat suitability for cutthroat trout, test empirically derived SI's with SI's from an independent set of data, and compare HSI's calculated from three different approaches with those derived by dividing observed standing crop by maximum standing crop. The authors used data collected for other studies in the Smith and South Coos drainages and the data from the Nestucca drainage described in the previous synopsis. Populations were estimated by removal techniques; habitat rating techniques varied somewhat between streams. Cutthroat trout had narrower habitat requirements when sympatric with competitors. Limiting factors between the two study creeks may be different.

The authors tested unpublished SI's that were similar to seven SI's from the published model: V1 (maximum temperature), V3 (minimum DO), V9 (substrate), V10 (percent pools), V13 (pH), V16 (percent fines), and V17 (percent shade). The unpublished SI graphs were used to compute predicted SI values, which were compared with "observed" SI's developed from Nestucca data (by dividing observed standing crop by maximum standing crop). The authors did not conduct comprehensive statistical comparisons, but concluded that there was a lack of correlation between predicted and observed SI's.

The authors evaluated three SI aggregation approaches: average value, interactive limiting factor, and lowest suitability index. The HSI's from the three

approaches did not have a strong positive correlation with observed HSI's. Low correlations may have been due to key habitat and biotic variables not being included in the tested models or to differences in data collection and variable definitions between the two studies. The authors did not address their assumption that dividing observed standing crop by maximum standing crop was the best approach for deriving an observed HSI.
Suggested revisions: None.

Reference: Persons, W. R., and R. V. Bulkley. 1984. Evaluation of the riverine cutthroat trout habitat suitability index model. Proceedings of a workshop on fish habitat suitability index models. U.S. Fish and Wildlife Service Biological Report 85(6):112–181.
Synopsis: Persons and Bulkley used field data from 24 sites in seven streams in Idaho, Nevada, and Utah. Populations were sampled by electrofishing with a two-step removal depletion method. Cutthroat trout SI's were compared with standing stock estimates of cutthroat trout, rainbow trout, and the two species combined. For comparisons of cutthroat trout biomass with SI values, correlation coefficients were ≤ 0.53, indicating a poor relation. Ten of the 14 comparisons had negative correlation coefficients. The SI's for average depth and average velocity during embryo development had significant ($P \leq 0.01$), yet negative, correlations.

The SI's were also evaluated by plotting data against a theoretical 45° regression line based on the maximum biomass (14.6 g/m^2) for rainbow trout in optimum habitat, and 0.05 g/m^2 biomass in unsuitable habitat. The authors assumed that an accurate SI should result in data points on or below the line. Points below the line may also be due to interactions among other variables. For temperature, embryo velocity, percent cover, substrate for juvenile cover, and percent pool, SI's were fairly accurate because nearly all data were on or below the line. Data above the line were frequently from Gance Creek, which contains a hardy subspecies; this may explain why these sites supported high biomass in suboptimum habitat. For five SI's, Gance Creek data were responsible for nearly all cutthroat trout data above the theoretical line. Because the rainbow trout HSI model is similar to the cutthroat trout model, the authors compared cutthroat trout SI's with rainbow trout biomass. The rainbow trout data produced low correlation coefficients (<0.6).

The lack of biomass estimates for each life stage required an assumption of constant recruitment and evaluation of early life stage component HSI values with adult and juvenile biomass estimates. The authors concluded that there were no significant positive correlations between life stage component ratings and biomass and that the life stage aggregation techniques were invalid. All correlations between cutthroat trout biomass and HSI values were negative. Thus, they concluded that the HSI model is weak, especially in combining SI's into life stage components and components into a single HSI.
Suggested revisions: Variables accounting for upstream migration barriers, winter ice scouring, and species interactions should be added to the model. Subspecies of cutthroat trout may have different habitat requirements and may require unique SI's.

Fallfish (Semotilus corporalis)

Summarized by: Jeanette Carpenter

Reference: Trial, J. G., C. S. Wade, and J. G. Stanley. 1984. HSI models for northeastern fishes. Proceedings of a workshop on fish habitat suitability index models. U.S. Fish and Wildlife Service Biological Report 85(6):17–56.
Synopsis: A fallfish model was developed from the literature and was to be field tested by collecting habitat and standing stock data during low summer flow from 11 stream sections in Maine. Fallfish were not found in any of the stream sections, so the model was not tested.

Suggested revisions: None.

Gizzard Shad (Dorosoma cepedianum)

Summarized by: Jeanette Carpenter

Reference: Rabern, D. A. 1984. Development of habitat based models for predicting standing crops of nine species of riverine fishes in Georgia. M.S. thesis, University of Georgia, Athens. 127 pp.
Synopsis: Rabern developed and tested an alternate model using readily available or easily predicted parameters to predict standing stock for nine riverine species in Georgia. The data base consisted of 32 survey stations and 20 independent variables. Population data were collected using rotenone. Standing stock was in units of total weight collected per sample area. Most physical data were collected at the time of the rotenone surveys. Chemical data were obtained from USGS publications. Biological variables used in the model were species diversity and distance from the center of the species' natural range.

Rabern used the stepwise method of minimum R^2 improvement to build multiple regression models. Owing to costs of collecting data, Rabern stated that a model should include as few variables as possible. He made

various modifications to reduce the number of variables considered. Adequacy of a model was determined using R^2 and C_p statistics. Five adequate models were developed for each species, based on five sets of data: the original data, two sets based on correlation coefficients and associated squares and cross products, and two sets based on significance level and associated squares and cross products. The model that had the highest correlation coefficient was selected as the best model.

For gizzard shad, the original set of data provided the highest correlation coefficient and thus was considered the best model ($R^2 = 0.96$, $P = 0.0001$). This model used 12 variables related to width, depth, monthly flow, mean annual air temperature, water quality, and DO. Rabern included a discussion of the biological importance of the 12 variables. Rabern tested the model by comparing predicted estimates with actual standing stock estimates determined from two sites that were not used in model development. The gizzard shad model predicted standing stock estimates of 15.78 and 16.39 kg, while the actual standing stock estimates at the two sites were 4.99 and 15.8 kg, respectively. Rabern concluded that the model closely predicted actual estimates; however, no statistics were used to support this conclusion.
Suggested revisions: None. Regression models are offered as an alternative.

Green Sunfish (Lepomis cyanellus)

Summarized by: Jeanette Carpenter

Reference: Gilbert, R. J. 1984. Assessments of selected habitat suitability index (HSI) models. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):275–390.
Synopsis: Data collection and analysis techniques were the same as described in the synopsis for the publication under black bullhead.

Three of the six reservoirs sampled were within the native range of green sunfish; the other three reservoirs had introduced populations. Green sunfish HSI's from the reservoir model were poorly correlated with estimated standing stocks ($r = 0.370$, $P = 0.470$). Although green sunfish occurred in all reservoirs, four had HSI values of zero, due to maximum temperatures in littoral areas exceeding 31°C during spawning (V9) and excessive reservoir drawdown during spawning (V17). The model may be too stringent for these variables, although removing them did not improve model performance. The six rivers were outside the native range of green sunfish. All six rivers had HSI values of zero due to the high water velocities in pools during spawning. Only one river had green sunfish, and the standing stock was very low.
Suggested revisions: The reservoir model variables should be more flexible, especially those associated with maximum temperature and drawdown effects during spawning.

Reference: Layher, W. G., and O. E. Maughan. 1984. Analysis and refinement of habitat suitability index models for eight warmwater fish species. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):182–250.
Synopsis: The same data and similar results described for this study are also presented in Layher (1983). The authors developed and tested their own HSI models. A set of data containing habitat variables and fish biomass estimates from 420 Kansas stream sites was used for several analyses. A presence-absence model was developed. Eight new SI graphs were developed; the new SI values and standing stock data were used in a stepwise regression to develop biomass models. Draft SI's that were available prior to model publication were visually compared with the new SI graphs. The presence-absence and biomass models were tested with similar data from 50 Oklahoma stream sites. The Kansas data were collected by different researchers, using several fish collection methods, over several years. The Oklahoma data were collected by one group of researchers during one summer, and only one fish-sampling method was used (electrofishing with multiple depletion passes).

The presence-absence model developed from Kansas data correctly predicted green sunfish presence 89% of the time; however, only 44% of sites without green sunfish were classified correctly. The accuracy of the Kansas model was reduced when applied to Oklahoma data; an Oklahoma-based model misclassified similar numbers of sites.

Standing stock estimates varied depending on the type of capture method used. When the entire set of Kansas data was used, there were no significant relations between individual species's standing stocks and SI values for abiotic variables. However, when each capture method was analyzed separately, six of the eight capture methods yielded significant stepwise regression models. Each regression model contained different combinations of abiotic variables. Kansas regression models applied to Oklahoma data produced no significant correlations between predicted and observed biomass. An attempt to produce a separate Oklahoma model using SI curves developed from the Kansas data to assign SI's to Oklahoma habitat failed to yield a significant model.

Individual SI's developed from the Kansas data were very similar to published SI's developed from literature reviews. This similarity supports the approach used to develop SI's. Researchers are more likely to develop an

accurate habitat suitability model for species that require narrower environmental conditions than the green sunfish. Reliable models may only be built over small, homogeneous geographical areas. Researchers need to address synergistic effects of variables; there is no clear method to aggregate SI's into an HSI.

Suggested revisions: The temperature SI (V7) graph may need to be shifted to show optimum temperatures between 20° and 30°C. The SI for average current velocity within pools (V11) may need to be redefined as average stream velocity and the optimal velocity range extended to 40 cm. The upper limit for this graph may need to be changed to 100 cm.

Reference: Layher, W. G., and O. E. Maughan. 1987. Modeling habitat requirements of a euryhabitat species. Transactions of the Kansas Academy of Science 90(1–2):60–70.

Synopsis: This publication is based on essentially the same data described in the previous synopsis and presents similar results and conclusions. There was no significant correlation between estimated standing stocks from Oklahoma and standing stocks predicted by the Kansas models. To produce a separate Oklahoma model, suitability index graphs developed from the Kansas data were used to assign SI's to Oklahoma habitat. Stepwise regression analysis of the Oklahoma data did not result in a significant model.

Abiotic habitat variables may not explain green sunfish occurrence or variations in biomass because the species is a habitat generalist. Other potential reasons for model failure include the following: limiting variables were not included in the models, summer is not a limiting season for green sunfish, and biological factors may be limiting. The last possibility is considered more likely than the others.

Suggested revisions: Presence-absence models, regression models, and revised SI's are presented as alternatives.

Lake Trout (Salvelinus namaycush)

Summarized by: Jeanette Carpenter

Reference: Alt, K. T. No date. Evaluation of the HSI model for lake trout--relationship to Alaskan project impacts. Unpublished final report to the U.S. Fish and Wildlife Service, Alaska Fish and Wildlife Research Center, Anchorage.

Synopsis: This report summarizes the life history of lake trout in Alaska and evaluates the HSI model relative to Alaskan project impacts. The published HSI model was not tested with field data but was evaluated based on the authors' experience and knowledge of the species. The paper is undated but probably written in 1994.

The temperature SI should have two parts, a minimum fall-winter temperature SI and a maximum summer temperature SI. The word hypolimnion should be removed because Alaskan lake trout seek warmer water in the summer. Intermediate values in the oxygen SI histogram should be removed because of lack of information for Alaskan populations. Food items other than fish are often utilized by Alaskan lake trout; thus, the forage food SI should reflect not just forage fish but the entire forage base. Lake trout spawn in many Alaskan lakes that have only gravel, sand, and silt; the spawning substrate SI should reflect these differences.

I believe there are major errors in the logic Alt used to revise the temperature SI's. The text states that the minimum fall-winter temperature SI (V1a) should have an SI of 1.0 when temperatures are $\geq$4°C and should decrease linearly to an SI of zero at temperatures <4°C. This would produce a nonsensical graph (e.g., 4°C has an SI of 1.0 and 3.9 has an SI of zero). However, the graph of V1a differs from the text description. The graph of V1a shows SI values are 1.0 at temperatures $\geq$8°C, decreasing linearly to an SI of zero at temperatures $\leq$4°C. At first glance this graph may make sense; however, it is for fall and winter temperatures. Alaskan lakes with minimum fall-winter temperatures <4°C are not likely to be unsuitable. The life history information provided in the text does not support these SI values. This graph is especially worrisome with respect to the SI for maximum summer temperatures (V1b). For V1b, SI values are 1.0 at temperatures <17°C, decreasing linearly to zero at temperatures from 17° to 23°C. Thus, based on the two SI graphs, a maximum summer temperature of 0°C is optimal, while a minimum fall-winter temperature of 3°C is unsuitable. Both of these revisions to temperature seem to be in error.

Suggested revisions: Extensive revisions to SI graphs and model structure.

Largemouth Bass (Micropterus salmoides)

Summarized by: Jeanette Carpenter

Reference: Layher, W. G., and O. E. Maughan. 1984. Analysis and refinement of habitat suitability index models for eight warmwater fish species. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):182–250.

Synopsis: The same data and similar results as described for this study are also presented in Layher (1983). The authors developed and tested their own HSI models and a presence-absence model. Twenty new SI graphs were developed using Kansas standing stock data. The new SI values and standing stock data were used in a stepwise regression analysis to develop biomass models for eight different fish collection methods. The presence-absence model and biomass models were tested with Oklahoma data. Draft SI graphs available prior to model publication were visually compared with the new SI graphs.

Mean values of 10 habitat variables were significantly different (*t*-tests) at sites where largemouth bass were present compared with sites where they were absent. The presence-absence model correctly classified sites with largemouth bass 90% of the time; however, only 48% of sites where largemouth bass were absent were classified correctly. Adding a velocity variable improved the model, resulting in correct classifications at 82% of sites with largemouth bass and 73% of sites without this species. The accuracy of this model was reduced when it was applied to Oklahoma data. A model based on Oklahoma data had better reliability at predicting presence or absence of largemouth bass; 84% of all sites were classified correctly.

Estimated standing stock varied by capture method. When the entire set of Kansas data was used, there were no significant relations between individual species's standing stocks and SI's for abiotic variables. When analyzed separately, six of the eight capture methods yielded significant stepwise regression models containing different combinations of abiotic variables. When applied to Oklahoma data, two models showed a significant correlation between predicted and observed biomass values ($r^2 = 0.42$ and 0.48, $P < 0.02$). A second biomass model was developed by assigning SI values to Oklahoma habitat data using SI curves developed with Kansas data and applying stepwise regression analysis. This model utilized nine SI variables ($r^2 = 0.60$, $P = 0.005$); it was not tested.

In general, individual SI's developed from Kansas data were very similar to SI's developed from literature reviews. This similarity supports the approach used to develop SI's. Researchers are more likely to develop an accurate habitat model for species that require a narrower range of environmental conditions than largemouth bass. Reliable models may only be built for small, homogeneous geographical areas. Also, researchers may need to address synergistic effects of variables, and there is no clear method to aggregate SI's into an HSI.

Suggested revisions: None. Regression models were presented as an alternative.

Reference: Gilbert, R. J. 1984. Assessments of selected habitat suitability index (HSI) models. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):275–390.

Synopsis: Data collection and analysis techniques and problems with model testing and HSI models in general are the same as described in the synopsis under black bullhead. All of the reservoirs and rivers sampled were expected to support largemouth bass. Reservoir HSI's from the draft model were poorly correlated with standing stocks ($r = -0.112$, $P = 0.833$). Sport harvest was probably more of a limiting factor than habitat in these reservoirs.

All six rivers had HSI values of zero due to the high water velocities in pools and backwaters, which resulted in a very poor correlation between estimated standing stocks (which ranged between 1.3 and 25.4 kg/ha) and HSI values. Many of the sampled areas had no pools or backwaters, which is typical of southeastern coastal plain rivers. Eliminating V20 (maximum current velocity at 0.8 depth within pools or backwaters during spawning) resulted in a higher correlation between HSI values and standing stocks ($r = 0.785$), although it was not significant ($P = 0.157$).

Suggested revisions: For the reservoir model, the food component should consider interspecific interactions among centrarchids by compensating for the variety of centrarchid species in a given reservoir. Largemouth bass standing stocks are relatively high in southeastern coastal plain rivers, even though these rivers typically have few pools or backwater areas with low velocities. The variable V20 should consider that largemouth bass find refuge in such areas; however, no specific revisions to the riverine model were suggested.

Reference: Nelson, D. A., and A. C. Miller. 1984. Application of habitat suitability index models for white crappie, bluegill, and largemouth bass. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):251–274.

Synopsis: Objectives, data collection, data analyses, and model modification techniques are as described for this study for bluegill. The first modification for the largemouth bass model was not described. The second modification used three original SI variables--percent lacustrine area ≤ 6 m deep (V2), percent cover for adults and juveniles (V3), and percent cover for fry (V4)--and a new SI variable, percent water >1.5 m deep (V_D). The new variable was based on an analysis of depth profiles and the observation that most pits <1.0 m deep dried out by fall. The second modification resulted in a higher cor-

relation between the observed standing stocks and HSI values ($r = 0.54, P < 0.005$). The authors concluded that HSI models work better with habitat specialists than with generalists. Other possible reasons for low correlation included fishing pressure, competition, farming and grazing practices, and spring flooding. The descriptive Additional Model 2 in FWS/OBS-82/10.16 was also tested. This model was not well correlated with observed standing stocks ($r = 0.16, P = 0.2$).
Suggested revisions: Add a variable reflecting percentage of deep water and remove several original variables.

Longnose Dace (Rhinichthys cataractae)

Summarized by: Jeanette Carpenter

Reference: Hubert, W. A., and F. J. Rahel. 1989. Relations of physical habitat to abundance of four nongame fishes in high-plains streams: A test of habitat suitability index models. North American Journal of Fisheries Management 9:332–340.
Synopsis: Data collection and analysis techniques are as described for this study for common shiner.

Longnose dace occurred in 27 stream sites. Habitat data were collected for five of the six HSI model variables. Two variables were positively correlated with longnose dace biomass: current velocity during spring and summer ($r = 0.05, P = 0.43$) and maximum depth of riffle ($r = 0.21,\ P = 0.46$). The HSI was not related to biomass ($r = -0.15, P = 0.178$). Possible reasons for model failure include different limiting factors in separate geographical areas and lack of testing of SI and HSI values with actual measurements of fish biomass.

Fourteen habitat variables were correlated with longnose dace biomass. Habitat variables selected for stepwise multiple regression analysis were correlated with standing stock but not with each other. Nine selected variables had significant ($P < 0.05$) positive correlations with longnose dace biomass (r^2 ranged between 0.15 and 0.35). One of these variables was a rating of the percentage of main-channel run habitat where reaches with <40% or >80% run habitat had a value of 0.25, and reaches with 40% to 80% run habitat had a value of 1.0. Stepwise multiple regression resulted in three significant models (each of which contained the main-channel run rating variable). The model with the highest correlation coefficient ($R^2 = 0.64; P < 0.001$) was as follows: longnose dace standing stock (g/m^2) = 2.34 + (0.039 x percent of backwater pools) + (0.013 x submerged aquatic vegetation) + (0.819 x rating of main channel run) + (0.003 x percent of overhanging cover) - (0.339 x pH). This regression model was not tested. Biological arguments for using the model were provided, as were literature citations for longnose dace biomass correlating with the four habitat variables.
Suggested revisions: None. The regression model is an alternative.

Northern Pike (Esox lucius)

Summarized by: Jeanette Carpenter

Reference: Alt, K. T. 1994. Evaluation of the habitat suitability index for northern pike in relation to Alaska project impacts. Unpublished report to the U.S. Fish and Wildlife Service, Alaska Fish and Wildlife Research Center, Anchorage.
Synopsis: Alt described project impacts typical of Alaskan waters, summarized life history information on northern pike in Alaska from published and unpublished sources, and provided an opinion on using the nine habitat variables of the original HSI model in Alaska. The original model was not tested with field data.
Suggested revisions: For percent of midsummer area with aquatic vegetation (V3), use slope B instead of slope A, and shift the SI for length of frost-free season (V6), depending if the site is in the interior or in the northern arctic. The graph does not agree with the text for V6. Because maximum summer temperatures in northern pike waters in Alaska are much cooler than those in other areas, revise V7 (maximal weekly average temperature of the surface layer) so that the SI graph shifts to the left, making optimal temperatures 16° to 25°C. Owing to the lack of empirical data on stream gradient in Alaskan waters, change V9 (stream gradient) to a straight-line graph.

In Alaska, nearly all total dissolved solids (TDS) concentrations are 16 to 80 ppm; thus, most Alaskan waters should have an SI rating of 1.0 for variable V4 (concentration of TDS in surface waters during midsummer). Therefore, delete V4 from the model. Most northern pike lakes in Alaska have pH levels that would also get an SI rating of 1.0. Although Alt did not suggest deletion of V5 (pH) from the model, he did recommend that future evaluations consider giving less weight to V5 (as well as to V6). A new variable, availability of DO at the site of overwintering (V10), should be measured in February and March.

Reference: Anderson, P. G. 1992. Adaptation of a habitat suitability model for prioritization of habitat rehabilitation needs of northern pike (*Esox lucius*). M.S. thesis, Trent University, Peterborough, Ontario, Canada. 96 pp + appendices.
Synopsis: The model was evaluated as a means of identifying limiting habitat parameters for developing a restoration plan for Hamilton Harbour, a large bay in

Lake Ontario, Canada. Application of the model to Hamilton Harbour indicated that lack of vegetation for spawning was limiting northern pike populations. The model did not contain specific information on the reproductive habitat (spawning and rearing) requirements of northern pike that could be used to develop a detailed plan describing the type and density of vegetation needed to rehabilitate reproductive habitat. A literature review indicated that there was insufficient information to develop additional suitability indices for young-of-year fish habitat requirements. Consequently, the authors conducted a trap netting study to characterize depth of nursery habitat, analyzed stomach contents to determine food preferences, and conducted a laboratory study to determine plant type and plant density preferences of young-of-year fish. These data were used to develop three new suitability indices, which were combined into a reproductive component to specify the water depth and vegetative characteristics necessary to insure successful spawning and subsequent rearing. The original model was then applied to the proposed rehabilitated conditions in Hamilton Harbour to determine what amount of rehabilitated spawning habitat was needed to support a productive northern pike population. Neither the new model component or the original model was tested against an independent data set.

Suggested revisions: Suitability index graphs are presented for three new variables: aquatic plant type available (four classes: robust, slender, mixed, and submerged), percent vegetative cover, and water depth. These variables are used as an additional component for the original model to provide an improved classification of quality of spawning and rearing habitat. The original model is still used to develop an overall rating of habitat quality.

Reference: Mestl, G., and J. Nickum. 1984. Evaluation and modification of habitat suitability index models for selected fishes in Midwest waters. Final report, Iowa Cooperative Fishery Research Unit, Ames. Cooperative Unit Agreement No. 14-16-0009-1503. 347 pp.

Synopsis: Mestl and Nickum tested the model for northern pike using four sets of data: Minnesota lakes, Wisconsin lakes, Iowa lakes, and Iowa rivers. They also developed models for predicting presence or absence of northern pike. Iowa data had qualitative abundance estimates (absent, low, medium, high), Minnesota data were catch/gill net lift, and Wisconsin data were number of fish/hectare. Minimal information was provided on specific techniques for estimating population size and measuring habitat.

The authors revised the original model to use habitat variables listed in the four sets of data. Because northern pike populations in Iowa are supplemented by stocking, the reproductive component of the model was not included in the tests that used Iowa data. Data from Minnesota lakes with nonreproducing populations of northern pike were also used to test a version of the model without a reproductive component. The Wisconsin data were used to test versions of the model with and without a reproduction component.

In all, six versions of the HSI model were tested. Two correlations between HSI and estimated abundance were significant ($P < 0.05$): Iowa lakes ($R^2 = 0.07$, $P = 0.01$, $n = 88$) and rivers ($R^2 = 0.15$, $P = 0.035$, $n = 30$). The R^2 values were low for all six HSI models, ranging between 0.008 and 0.15.

All four sets of data yielded significant ($P < 0.05$) regression models, with R^2 values ranging from 0.10 for the Minnesota model to 0.997 for the Wisconsin model. The regression models were tested with data sets not used in model development. Testing the Wisconsin model ($R^2 = 0.99$, $P = 0.0001$, $N = 10$) with the Iowa lakes data produced the only significant ($R^2 = 0.16$, $P = 0.0001$, $n = 86$) test for predicted versus actual northern pike abundance.

Suggested revisions: None. Regression models are presented as an alternative.

Rainbow Trout (Oncorhynchus mykiss)

Summarized by: Jeanette Carpenter

Reference: Unthank, A. S., and K. A. Holzer. No date. Evaluation of stream habitat variables for use in development of a habitat suitability index for juvenile steelhead, *Oncorhynchus mykiss*. Unpublished report, U.S. Fish and Wildlife Service, National Fishery Research Center-Seattle.

Synopsis: Published SI's were compared with SI's derived from 3 years' data for 22 Idaho streams. Eight variables were used in the comparison: maximum temperature (V1 and V2), percent instream cover (V6), substrate type (V9), percent pools (V10), percent ground cover along the bank (V12), pool class rating (V15), and percent fines (V16).

Empirical SI's were obtained by dividing observed standing stocks (estimated by snorkeling) by the maximum standing stock for each year. SI graphs were drawn by connecting lines through the highest SI values.

Two to nine habitat variables were measured per stream, and data from different streams combined to create several subsets. Empirically derived HSI's were compared with predicted HSI's using Spearman's rank correlation. Empirically derived SI's closely matched the published graphs for V1, V2, and V10, but failed to match for variables that were defined differently than in the published model. Problems with the data and variables

included small sample sizes, narrow observed ranges, and variables that were difficult to rate objectively. For several variables, the observed points occurred above the published SI graphs.

The authors evaluated three SI aggregation methods: interactive limiting factor, lowest SI, and average value. For interactive and average value methods, V12 and V15 contributed most to the predictions of observed HSI values, V6 contributed the least. The averaging predicted higher HSI's than interactive or lowest SI aggregation techniques. Areal densities were more highly correlated with predicted HSI than linear densities.

Single density estimates may misrepresent carrying capacity. The fact that few fish were present to utilize all available habitat may have confounded the study results.
Suggested revisions: None.

Reference: Meyer, J. H, J. M. Hiss, and R. S. Boomer. 1983. An application and assessment of a steelhead habitat model. Unpublished report, U.S. Fish and Wildlife Service, Fisheries Assistance Office, Olympia, Washington.
Synopsis: A draft version of the steelhead portion of the rainbow trout model was evaluated with habitat data collected from four sites in the high-quality Kalama River and three sites each in the low-quality North Fork Newaukum and White rivers. Macrohabitat and landscape characteristics were described for each site. No statistical comparisons were done; HSI's were evaluated based on the authors' opinions of habitat quality and steelhead populations.

The draft HSI model uses 18 variables. Six variables require information on water quality and flow. Data quality for these variables depended on access to USGS records. One variable (V5) was not measured, so it was removed from the analysis. The model minimized differences between the rivers; SI values for the 17 variables varied little among sites. Expected HSI's were 0.8 to 1.0 for the Kalama River, <0.5 for North Fork Newaukum River, and the White River. However, calculated HSI's did not follow this pattern. Primary differences were that the embryo component indices were 0.5 for the Kalama River and slightly higher for the other rivers, fry CI's were high for all three rivers, and juvenile CI was higher for the White River than for the other rivers. Possible explanations for these unexpected results were presented: the values associated with individual SI graphs may be inappropriate, the sample reaches may not have accurately represented the rivers, and variability in habitat characteristics may have been high.

Model weaknesses include the assumption that freshwater habitat requirements for steelhead are the same as for rainbow trout, the possibility that variables most critical to steelhead survival and productivity were not identified, and the inability of the model to capture the variable nature of coastal stream habitat. Habitat and life-history differences between anadromous and nonanadromous trout were described, and recommendations for changing or adding individual SI variables were provided. The draft model is difficult to use on glacial streams when visibility is low and on streams without water quality and flow records.
Suggested revisions: Significant differences between anadromous and nonanadromous trout warrant consideration of separate models. The range of suitable values should be reconsidered, especially for summer low flow (V14). Allochthonous input (V11), DO, and pH are probably not limiting in northwestern streams. The model should incorporate riverine features important to anadromous trout, including tributary habitats. Greater weight should be given to V14. Streambank stability (V12) is an unreliable variable because localized slides can impact downstream areas for miles.

Red Drum (Sciaenops ocellatus)

Summarized by: Carroll L. Cordes

Reference: Funicelli, N. A. 1994. Revised habitat suitability index model: Larval and juvenile red drum. Unpublished report, National Biological Service, Southeastern Biological Science Center, Gainesville, Fla.
Synopsis: The author used the Delphi technique and a panel of eight experts to evaluate and revise the model. The evaluation and revision process focused primarily on the larval stages of the red drum.
Suggested revisions: Because the original red drum model did not clearly define the larval stage, a separate model for pelagic larvae and two models for demersal larvae were recommended. Two separate demersal larvae models were recommended because some estuarine areas have vegetated substrates and others do not. In all three revised models, variables are combined into separate life requisite components.

Several new variables, including water depth and substrate type, distance from maximum extent of flood tide, and distance from nearest tidal pass or known spawning site, should be added to the model. The three revised models define HSI as the lowest life requisite value.

Redbreast Sunfish (Lepomis auritus)

Summarized by: Jeanette Carpenter

Reference: Helfrich, L. A., K. W. Nutt, and D. L. Weigmann. 1991. Habitat selection by spawning redbreast sunfish in Virginia streams. Rivers 2:138–147.

Synopsis: Habitat measurements at 128 nest sites were compared with measurements at 128 randomly determined non-nest sites in 10 Virginia streams. Study sites were selected based on redbreast sunfish abundance reported from other studies; thus, all of the study sites presumably represented optimum habitat. The authors graphically compared optimum ranges for SI's with relative frequency of nest and nonnest sites for the reproductive component of the HSI model but did not apply statistical tests. Results were similar to the published SI's for mean water temperature, water depth, and amount of cover. The published SI for V5 indicates optimal values for current velocity when 65% of the stream area has velocities ≤20 cm/s, yet more than 85% of nests were in water with velocities <3 cm/s. The authors cited two other studies in which nests occurred in slower current velocities than presented in the model.

The authors concluded that their substrate sizes had a narrower range than the optimal SI for substrate (V6); however, their results do not support this claim. The published model provided that optimal areas have at least 40% of the substrate composed of particles 1–5 mm in diameter, or coarse sand and fine gravel. The authors reported mean substrate sizes of 0.5–16 mm; 29% were coarse sand (0.5–2.0 mm) and 39% were fine gravel (2.1–8.0 mm). The sum of these percentages is 58%; therefore the nests were in the optimum habitat range defined by the model. The authors incorrectly cited the published SI as indicating that optimal particle sizes are between 0.6 and 16 mm. This size range is not in the SI and is nearly identical to their mean range (0.5–16 mm). Their optimum percent of sand and gravel is higher than the published SI. However, they measured substrate after the nests were prepared by male redbreast sunfish. The fish may have altered substrate composition by removing the finer sediment.

Although the authors stated that their results were similar to the SI for cover, I believe there are marked differences. The SI for hard structure cover (V1) has optimal values between 25% and 75%. They determined hard structural cover was 17% and aquatic vegetation 13% at nest sites, and reported the total cover as being similar to optimal SI values. However, the published SI is for hard structure cover only.

Suggested revisions: Maximum current velocity (V5) should be changed from ≤20 cm/s to <3 cm/s for the reproductive component of the model.

Smallmouth Bass (Micropterus dolomieu)

Summarized by: Jeanette Carpenter

Reference: McClendon, D. D., and C. F. Rabeni. 1987. Physical and biological variables useful for predicting population characteristics of smallmouth bass and rock bass in an Ozark stream. North American Journal of Fisheries Management 7:46–56.

Synopsis: McClendon and Rabeni did not test published models but developed and evaluated their own predictive equations to relate habitat variables to population characteristics. They used data on 32 physical and biological variables from 20 sites on the Jacks Fork River, Missouri. They sampled during summer in 1982 and 1983 (10 sites per year). Smallmouth bass populations were estimated using electroshocking and mark-recapture techniques. Data from 1982 were used to examine correlations between input variables and four population variables: biomass, density, condition factor, and proportional stock density. Attribute pairs with absolute correlation coefficients of 0.3 were selected for model-building trials using various multiple-regression analyses (forward, backward, and stepwise). Predictor variables were limited to two. Tests of statistical validity of the equations included testing for linear relations, comparing predicted values from 1982 with actual values from 1983, and calculating bias and relative bias.

Multiple regression analysis yielded three significant ($P \leq 0.05$) bivariate models from the 1982 data: (1) density (fish/ha) = 43.855 + (578.439 x area of boulder substrate) + (5.786 x area of undercut bank), $R^2 = 0.62$; (2) condition factor = 88.323 - (0.319 x maximum summer temperature) + (0.0001 x crayfish density), $R^2 = 0.80$; and (3) proportional stock density = 5.988 + (0.084 x total area of woody structures) + (0.0263 x total area of vegetation), $R^2 = 0.59$. Thus, condition factor, density, and proportional stock density were linearly related to physical habitat characteristics. The fourth model was marginally significant ($P \leq 0.10$): biomass (kg/ha) = 12.318 + (1.310 * area of undercut bank) + (74.338 * area of boulder substrate), $R^2 = 0.56$.

To test equation accuracy, the authors compared observed values in 1983 with values predicted by the model developed from the 1982 data. The correlation between predicted and observed biomass was significant ($P \leq 0.05$, $r = 0.81$) but affected by one outlier. This same approach resulted in significant ($P \leq 0.05$) correlations between observed and predicted density ($r = 0.87$) and condition factor ($r = 0.91$). Proportional stock density had low accuracy ($P > 0.05$; $r = 0.66$), possibly due to size limits on angler harvest. McClendon and Rabeni suggest that when minimum environmental conditions such as depth and flow are met, cover variables become more important. The authors also discussed the ecological implications of their models.

Suggested revisions: None. Regression models were presented as an alternative.

Spotted Bass (Micropterus punctulatus)

Summarized by: Jeanette Carpenter

Reference: Layher, W. G., and O. E. Maughan. 1985. Spotted bass habitat evaluation using an unweighted geometric mean to determine HSI values. Proceedings of the Oklahoma Academy of Sciences 65:11–17.
Synopsis: Standing stock and habitat data were collected from 11 stream sites in northern Oklahoma during summer 1981. Adults were sampled by electroshocking, and populations were estimated by three-pass (or more) depletion sampling and application of maximum likelihood estimators. One to 11 adults were collected at each site. Maximum likelihood estimates indicated a high probability that all adult fish were captured at a site. Population estimates were used with average weights to estimate biomass at each site. Physical measurements were collected along three transects at each site. The authors used unpublished SI's that were similar to the published SI's and computed HSI's as geometric means of SI's for DO, gradient, substrate, water temperature, and velocity. Sites were ranked twice: one ranking was based on calculated HSI values, and the other ranking was based on estimated standing stocks. There was no correlation (Spearman's rho) between rankings based on HSI values and those based on standing stock.

The variables used in this model may not have been appropriate. Selecting variables is of critical importance, and the rationale for selecting model variables should be studied further. Numerous variables may limit or influence population instantaneously; thus, the chances of correlating biomass and physical factors in a given period are low. Correctly weighting each SI in the HSI formula needs further consideration. The model may have failed because the geometric mean formula assumes equal weighting.

Reference: Layher, W. G., and O. E. Maughan. 1984. Analysis and refinement of habitat suitability index models for eight warmwater fish species. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):182–250.
Synopsis: The same data and similar results are also presented in Layher (1983). Draft SI's were tested with standing stock data from a subset of 420 Kansas stream sites. The authors also developed and tested their own HSI model. Seven new SI graphs were visually compared with draft SI's and used in a stepwise regression analysis to develop biomass models. A presence-absence model was developed using discriminant function analysis. New models were tested with similar data from Oklahoma streams. Kansas data were collected by different researchers, using several fish collection methods, over several years. Oklahoma data were collected by one group of researchers during one summer, and only one fish-sampling method was used (electrofishing with multiple depletion passes).

Four literature-based draft SI graphs were used to assign SI's to Kansas stream sites for each of the four variables, and HSI's were determined using a geometric mean model. There was no correlation between HSI and spotted bass standing stock.

The presence-absence model yielded correct predictions 81% of the time; nearly all of the misclassified sites were sites without spotted bass that had appropriate habitat but were beyond the species' natural range. The Kansas model was inaccurate when applied to Oklahoma data. A model based on Oklahoma data produced more reliable predictions of presence or absence.

The complete set of Kansas data produced no significant stepwise regression models correlating biomass with SI variables. However, when analyzed separately, five of the eight capture methods yielded significant models. Each model contained different combinations of variables. When models based on Kansas data were applied to Oklahoma data, there was no significant correlation between predicted and observed biomass. A significant biomass model with seven variables was developed by using SI graphs developed with Kansas data to rate Oklahoma habitat and then applying stepwise regression to the ratings. This model was not tested with independent data. General comments on model building and testing are described in the synopsis for this study for green sunfish.
Suggested revisions: None. Regression models were presented as an alternative.

Reference: Layher, W. G., O. E. Maughan, and W. D. Warde. 1987. Spotted bass habitat suitability related to fish occurrence and biomass and measurements of physicochemical variables. North American Journal of Fisheries Management 7:238–251.
Synopsis: This paper is based on the same data, uses similar analysis techniques, and presents similar results as described in the previous synopsis.

I found some inconsistencies in the description of the models. For Kansas data, the authors noted that recaptures by rotenone were most reliable. The Kansas biomass model (equation 1) was described as using data from "this method." However, Table 7 of the paper describes two methods ending with rotenone recapture that pro-

duced significant biomass models, and neither model had variables exactly matching those in equation 1. The first model in Table 7 more closely matches the equation in the text, yet the equation is incomplete because the coefficient for the mean depth SI is missing. I compared the Kansas equation, correlation coefficients, and significance levels in this paper with those in the authors' other paper (previous synopsis) and they are identical (except for the inclusion of a seventh variable), as is the information in Table 7. Why mean depth was left out of the Kansas equation is not clear.

Suggested revisions: None. Regression and discriminant function models are presented as alternatives.

Spotted Seatrout (Cynoscion nebulosus)

Summarized by: Carroll L. Cordes

Reference: Shutters, M. K. 1993. Revised habitat suitability index model: Spotted seatrout. Unpublished report, National Biological Survey, Southeastern Biological Science Center Laboratory, Gainesville, Fla.

Synopsis: A literature review was used in combination with a panel of experts to evaluate and recommend improvements to the published model. A subjective rating of the expected responsiveness of each model variable to five different habitat modifications known to influence seatrout densities was used to evaluate the model. Variables tested included salinity, temperature, and emergent/submergent cover.

Expected overall model performance varied among the five habitat modifications. Model variables were judged to be most responsive to the effects of impoundment actions on seatrout populations and least responsive to nutrient enrichment actions.

Suggested revisions: Based on model performance, reviews of recent literature, and opinions of the panel of experts, the author recommended model revision. Like the original, the revised model consists of water quality and food/cover components, and the overall HSI score is the lowest score for either water quality or food/cover.

The revised water quality component has three variables. Variable 1 is the percent of the year with water temperature between 24° and 32°C. The SI for this variable is zero at zero percent and 1 at greater than 50% of the year. Variable 2 is the percent of the year with water temperatures below 16°C; the SI is 1 at zero percent of the year, with a linear decrease to zero at 100%. Variable 3 is the percent of the spawning season with salinities between 17 and 32 ppt; the SI is zero at 0% and 1 at 100%.

For the food/cover component the author recommended replacing the original model variable with Variable 4, the percentage of emergent edge (first 3 m of marsh). Model users should consider the presence and type of impoundments that may occur in a study area. Impoundments may block movements of spotted seatrout and prey species.

Caution is recommended when applying the revised model north of South Carolina because little research has been done on habitat use by seatrout along the northern Atlantic coast.

Striped Bass (Morone saxatilis)

Summarized by: Jeanette Carpenter

Reference: Rago, P. J., and R. M. Dorazio. 1988. Evaluation of a habitat suitability index for coastal stocks of striped bass. Unpublished report, U.S. Fish and Wildlife Service, National Fisheries Research Center-Leetown, Kearneysville, W. Va.

Synopsis: Rago and Dorazio tested the larval component in FWS/OBS-82/10.85, which uses the geometric mean of SI's for temperature, salinity, and DO concentration and the arithmetic mean of SI's for two food-related variables (relative input of freshwater and relative amount of unspoiled salt marsh). The authors used 77 larval bioassay experiments conducted on spawning tributaries in Chesapeake Bay to develop linear regressions comparing the HSI's based on water quality data with larval survival rates.

They did not find a linear relation between larval survival and HSI. Influence plots indicated that the zero HSI values strongly influenced the regression equation, especially when zero HSI values corresponded to maximum survival rates. The authors explored alternative models based on water quality and survival data. Low pH range and high conductivity were highly correlated with high survival of larvae. The authors used response surface techniques to examine joint effects of conductivity and pH on survival. A logistic regression model indicated that survival reached a maximum value when conductivity was 1,000 mhos/cm and the pH was stable.

Rago and Dorazio attempted to revise the original HSI model. Zero HSI values, which strongly influenced the poor correlation of HSI with larval survival rates, were due to high threshold values for the SI's of temperature and salinity. Therefore, they modified the SI graphs by substituting conductivity for salinity and lowering the temperature threshold to 9°C. The correlation between the revised HSI model and survival rates was much improved. However, the slope of the regression equation was still significantly different from one, so the revised model was not considered valid. Organic and inorganic contaminants may explain

additional variation in the regression model. Limitations of the HSI model include an arbitrary aggregation method, a high sensitivity to threshold levels in the component variables, and inclusion of variables that are not reliably measurable. There needs to be an underlying statistical basis in the HSI to allow formal comparisons between HSI predictions and null HSI distributions. Population modeling should be used to evaluate the anticipated relationship between the HSI and some measure of population status. In general, the HSI model should not be used.

Suggested revisions: Other variables, such as contaminants, should be considered in model development.

Walleye (Stizostedion vitreum)

Summarized by: Jeanette Carpenter

Reference: Mestl, G., and J. Nickum. 1984. Evaluation and modification of habitat suitability index models for selected fishes in Midwest waters. Unpublished report, Iowa Cooperative Fisheries Research Unit, Ames. Cooperative Unit Agreement No. 14-16-0009-1503.

Synopsis: The model was tested with four data sets: Minnesota, Wisconsin, Iowa lakes, and Iowa rivers. Iowa data had qualitative abundance estimates (absent, low, medium, high). Minnesota data were catch/gill net lift, and Wisconsin data were number of fish per hectare. The authors modified existing models, developed new models when existing ones were unreliable predictors, and developed models for predicting presence-absence. Published models were revised to use variables in the four sets of data. Nonreproducing populations of walleye were tested with a model without a reproductive component. The R^2 values for correlations between HSI and abundance ranged from 0.001 to 0.13.

New stepwise regression models were developed with the four sets of data, yielding significant ($P < 0.05$) models with R^2 values ranging from 0.54 for the Minnesota model to 0.997 for the Wisconsin model. Four tests produced significant correlations between predicted and actual walleye abundance: testing the Minnesota model with the Iowa lakes data, testing the Wisconsin model with the Iowa lakes data and the Minnesota data, and testing the Iowa lakes model with the Minnesota data. In general, the correlations for these tests were low, possibly due to variation in walleye abundance from natural fluctuations and exploitation.

Suggested revisions: The published HSI models are burdened by highly specific variables (e.g., DO levels over spawning grounds for walleye), which makes them impractical. Including alternate or general habitat variables that are more commonly measured would make the models more useful.

Reference: Holland-Bartels, L. E., and M. R. Dewey. 1989. Applicability of the walleye HSI model information to the upper Mississippi River: Reproductive component. Unpublished report, U.S. Fish and Wildlife Service, National Fisheries Research Center, La Crosse, Wisconsin.

Synopsis: The authors evaluated the effectiveness of the walleye model in the Upper Mississippi River, which is considered representative of other large river systems. They focused on variables in the reproductive component that describe spawning habitat and water level, summarized literature that related to spawning and habitat use by walleye, and analyzed hydrologic data (river discharge and pool elevation) by pool and year. Egg collections and concurrent habitat measurements were made at a number of stations where other biologists had previously identified spawning in flooded grasses.

Minimum DO in spring (V7), mean weekly water temperature in spring (V10), and minimum winter water temperature (V11) do not limit walleye reproduction. Walleye in the upper Mississippi River spawn in deep main channel borders and shallow flooded terrestrial habitats; therefore, the spawning habitat index (V12) is not useful because it is heavily weighted toward shallow gravel/rubble areas. Also, water level changes during spawning and embryo development (V13) apparently do not affect year-class strength. The authors concluded that the reproductive component of the model is inadequate for use in the upper Mississippi River and that a lack of information precludes development of new SI's for reproductive component variables in that system.

Suggested revisions: None.

Warmouth (Lepomis gulosus)

Summarized by: Jeanette Carpenter

Reference: Gilbert, R. J. 1984. Assessments of selected habitat suitability index (HSI) models. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):252–275.

Synopsis: Data collection and analysis techniques and problems with model testing and HSI models in general are the same as described in the synopsis for black bullhead.

Because warmouth occur naturally in the study region, all sample sites were expected to support this species. Standing stock data were evaluated in four of

the six reservoirs; the other two reservoirs had unusable data, probably because populations were too low. Reservoir HSI's were poorly correlated with estimated standing stocks ($r = 0.196, P = 0.674$). Competition with other centrarchids may be more of a limiting factor than habitat in the reservoirs. All six rivers contained warmouth but had HSI values of zero because water velocities at 0.6 depth exceed 16 cm/s during average summer flow (V11). Eliminating V11 improved the correlation between HSI and standing stock ($r = 0.446$), but it was still not statistically significant ($P = 0.375$).

Reference: Rabern, D. A. 1984. Development of habitat-based models for predicting standing stocks of nine species of riverine fishes in Georgia. M.S. thesis, University of Georgia, Athens. 127 pp.

Synopsis: Rabern developed and tested an alternate standing stock model for nine riverine species in Georgia using readily available or easily predicted parameters. Data collection and analysis techniques are as described for this study under gizzard shad.

Five models were developed based on five sets of data: the original data, two sets of data based on correlation coefficients and associated squares and cross products, and two sets of data based on significance level and associated squares and cross products. The model that had the highest correlation coefficient was selected as the best model.

For warmouth, the model that used the data produced with squares and cross products provided the highest correlation coefficient ($R^2 = 0.95$, $P = 0.0001$, $N = 25$). This model used three independent variables: mean annual specific conductivity (V7), mean annual alkalinity (V15), and species diversity (V19). The chemical variables were significantly correlated with warmouth abundance. Rabern tested his model by comparing predicted estimates with standing stock estimates from two sites that were not used in model development. The warmouth model predicted standing stocks of 112.56 and 77.02 kg/ha; actual standing stocks were 0.48 and 1.40 kg/ha, respectively.

Suggested revisions: None. Regression models are presented as an alternative.

White Crappie (Pomoxis annularis)

Summarized by: Jeanette Carpenter

Reference: Layher, W. G., and O. E. Maughan. 1984. Analysis and refinement of habitat suitability index models for eight warmwater fish species. Proceedings of a workshop on fish Habitat Suitability Index models. U.S. Fish and Wildlife Service Biological Report 85(6):182–238.

Synopsis: Data and results are similar to Layher (1983). This study uses the same data base and analytical approach as described in the synopsis on spotted bass. A presence-absence model developed from Kansas data correctly predicted sites where white crappie were present 89% of the time; however, only 50% of sites where white crappie were absent were classified correctly. The accuracy of the Kansas model for presence-absence was much lower when applied to Oklahoma data.

Analysis of the entire set of Kansas data yielded no significant correlations between standing stocks and SI's for abiotic variables. However, when analyzed separately, six of the eight capture methods yielded significant stepwise regression models, each with different combinations of abiotic variables. Capture methods that ended with a kill technique were determined to be most accurate; these data resulted in a significant, five-variable model ($R^2 = 0.45$; $P < 0.01$; $N = 31$). When this model was applied to Oklahoma data, there was a significant correlation between predicted and observed biomass ($r^2 = 0.52$; $P < 0.04$; $N = 16$). The SI graphs developed from Kansas data were used to assign SI's to Oklahoma data. Regression analysis resulted in a significant univariate model using SI values for mean width ($r^2 = 0.27$, $P < 0.04$). In general, SI's developed from the Kansas data were similar to published SI's developed from literature reviews. This similarity supports the approach used to develop SI's.

General comments on model building and testing are as described in the synopsis for this study for green sunfish.

Suggested revisions: None. Regression models are presented as an alternative.

Reference: Nelson, D. A., and A. C. Miller. 1984. Application of habitat suitability index models for white crappie, bluegill, and largemouth bass. Proceedings of a workshop on fish habitat suitability index models. U.S. Fish and Wildlife Service Biological Report 85(6):251–274.

Synopsis: Objectives, data collection, data analysis, and model modification techniques are as described for this study for bluegill.

Borrow pit data were used to test 11 lacustrine model variables. To calculate an HSI, SI's of zero were changed to 0.05. White crappie standing stocks had a low correlation ($r = 0.34$, $P = 0.5$) with the HSI. Twenty-four pits had HSI values between 0.05 and 0.20. In most pits with viable fish populations, the maximum midsummer

littoral zone temperatures ranged from 28° to 34°C, which the model rated as having low suitability. These temperatures were apparently not limiting.

A new SI variable, percent water >1.5 m (V_D) was added based on an analysis of depth profiles and because most pits <1.0 m deep dried out by fall. The low correlation between HSI and standing stocks may be due to the relative distribution of white crappie; they occurred in nearly all of the borrow pits at much higher biomass levels than the other two fish species. The descriptive Additional Model 2 in FWS/OBS-82/10.7 was not well correlated with observed standing stocks ($r = 0.16$; $P = 0.2$).

Suggested revisions: The temperature suitability index skewed HSI's towards zero due to the high summer water temperatures. Eliminating this variable allowed other variables to influence the final HSI. A three-variable model (percent cover, percent littoral area, and percent deep water) is recommended.

White Sucker (Catostomus commersoni)

Summarized by: Jeanette Carpenter

Reference: Hubert, W. A., and F. J. Rahel. 1989. Relations of physical habitat to abundance of four nongame fishes in high-plains streams: A test of habitat suitability index models. North American Journal of Fisheries Management 9:332–340.

Synopsis: Data collection and analysis techniques are the same as described in the synopsis for common shiner. White sucker were found in 27 stream sites. Six of the 10 habitat variables used in the published model were tested. Only two variables showed a positive correlation with standing stock: water temperature at midafternoon during July and August ($r = 0.07, P = 0.014$), and percent pools during average summer flow ($r = 0.31, P = 0.003$). The resulting HSI's were not related to biomass ($r = 0.06$, $P = 0.572$). Possible reasons for model failure include different limiting factors in separate geographical areas and lack of initial testing of SI and HSI values with actual measurements of fish biomass. The assignment of an SI of 1.0 to the 10 missing variables in developing the HSI scores was not discussed as a possible reason for model failure.

Twelve habitat variables were correlated with white sucker biomass. Five that were not correlated with each other were selected for stepwise multiple regression analysis. Univariate regression equations are presented. The five variables -- percent of main channel run habitat, percent shade, Jackson turbidity units, water temperature in mid-August, and percent of large woody debris -- yielded two multiple regression models: standing stock (g/m^2) = 14.8 - (0.220 x water temperature) + (0.080 x large woody debris) - (0.099 x percent runs); $R^2 = 0.42$; $P \leq 0.005$; and standing stock (g/m^2) = 11.4 - (0.006 x Jackson turbidity units) + (0.073 x large woody debris) + (0.099 x percent runs); $R^2 = 0.40$; $P \leq 0.009$. The regression models were not tested. Biological justifications and literature citations are presented to support correlations with habitat variables.

Suggested revisions: None. Regression models are presented as an alternative.

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Appendix A. General description and full citations of all publications in the HSI model series.

General Description

The U.S. Fish and Wildlife Service published the "HSI model series" from 1982 through 1989. The series summarizes habitat requirements and describes Habitat Suitability Index models for selected individual species, species groups, and communities of mammals, birds, reptiles, amphibians, fishes, and invertebrates. The HSI model series Introduction (FWS/OBS-82/10) describes the purpose and scope of the series. Most subsequent publications were numbered consecutively (FWS/OBS-82/10.1, FWS/OBS-82/10.2, etc.) in order of publication. The series title was revised to Biological Report 82(10.**XX**) in Fiscal Year 1985. All HSI model series publications after FWS/OBS-82/10.85 have the "Biological Report" designation. [A single report, Biological Report 82(10.73), appears within the last group of publications to carry the FWS/OBS series designation.] The title change did not alter the scope of the series, and the consecutive numbering convention was retained.

Six reports in the HSI model series were revised in subsequent publications: FWS/OBS-82/10.3, revised as FWS/OBS-82/10.3A; FWS/OBS-82/10.19, revised as Biological Report 82(10.135); FWS/OBS-82/10.21, revised as Biological Report 82(10.98); FWS/OBS-82/10.28, revised as FWS/OBS-82/10.28 REVISED; FWS/OBS-82/10.30, revised as FWS/OBS-82/10.30 REVISED; and FWS/OBS-82/10.71, revised as Biological Report 82(10.124).

FWS/OBS-82/10.A describes guidelines for measuring aquatic habitat variables and modifying fish macrohabitat models. Biological Report 82(10.134) contains appendices of SI (suitability index) graphs presented as part of a description of how to use the Delphi technique to develop HSI models. There have also been numerous changes and updates to microhabitat curves presented in the series for use with the Instream Flow Incremental Methodology. These curves are maintained in a computer data base by the Biological Resources Division and are distributed without updating the HSI model series publications.

The HSI model series was discontinued in 1989. The last publication in the series was Biological Report 82(10.156). Since 1989, HSI models have occasionally appeared in other government publications.

Appendix A. Continued.

HSI Model Series, Alphabetical by Author:

Aggus, L. R., and W. M. Bivin. 1982. Habitat suitability index models: Regression models based on harvest of coolwater and coldwater fishes in reservoirs. U.S. Fish and Wildlife Service, FWS/OBS-82/10.25. 38 pp.

Aho, J. M., C. S. Anderson, and J. W. Terrell. 1986. Habitat suitability index models and instream flow suitability curves: Redbreast sunfish. U.S. Fish and Wildlife Service Biological Report 82(10.119). 23 pp.

Allen, A. W. 1982. Habitat suitability index models: Beaver. U.S. Fish and Wildlife Service, FWS/OBS-82/10.30. 20 pp.

Allen, A. W. 1982. Habitat suitability index models: Fox squirrel. U.S. Fish and Wildlife Service, FWS/OBS-82/10.18. 11 pp.

Allen, A. W. 1982. Habitat suitability index models: Gray squirrel. U.S. Fish and Wildlife Service, FWS/OBS-82/10.19. 11 pp.

Allen, A. W. 1982. Habitat suitability index models: Marten. U.S. Fish and Wildlife Service, FWS/OBS-82/10.11. 9 pp.

Allen, A. W. 1983. Habitat suitability index models: Beaver. U.S. Fish and Wildlife Service, FWS/OBS-82/10.30 Revised. 20 pp.

Allen, A. W. 1983. Habitat suitability index models: Fisher. U.S. Fish and Wildlife Service, FWS/OBS-82/10.45. 19 pp.

Allen, A. W. 1983. Habitat suitability index models: Mink. U.S. Fish and Wildlife Service, FWS/OBS-82/10.61. 19 pp.

Allen, A. W. 1983. Habitat suitability index models: Southern red-backed vole (western United States). U.S. Fish and Wildlife Service, FWS/OBS-82/10.42. 14 pp.

Allen, A. W. 1984. Habitat suitability index models: Eastern cottontail. U.S. Fish and Wildlife Service, FWS/OBS-82/10.66. 23 pp.

Allen, A. W. 1984. Habitat suitability index models: Gray partridge. U.S. Fish and Wildlife Service Biological Report 82(10.73). 23 pp.

Allen, A. W. 1985. Habitat suitability index models: American coot. U.S. Fish and Wildlife Service Biological Report 82(10.115). 17 pp.

Allen, A. W. 1985. Habitat suitability index models: Swamp rabbit. U.S. Fish and Wildlife Service Biological Report 82(10.107). 20 pp.

Allen, A. W. 1986. Habitat suitability index models: Lesser scaup (breeding). U.S. Fish and Wildlife Service Biological Report 82(10.117). 16 pp.

Allen, A. W. 1986. Habitat suitability index models: Mallard (winter habitat, Lower Mississippi Valley). U.S. Fish and Wildlife Service Biological Report 82(10.132). 37 pp.

Appendix A. Continued.

Allen, A. W. 1986. Habitat suitability index models: Mink, revised. U.S. Fish and Wildlife Service Biological Report 82(10.127). 23 pp.

Allen, A. W. 1987. Habitat suitability index models: Barred owl. U.S. Fish and Wildlife Service Biological Report 82(10.143). 17 pp.

Allen, A. W. 1987. Habitat suitability index models: Gray squirrel, revised. U.S. Fish and Wildlife Service Biological Report 82(10.135). 16 pp.

Allen, A. W., and R. D. Hoffman. 1984. Habitat suitability index models: Muskrat. U.S. Fish and Wildlife Service, FWS/OBS-82/10.46. 27 pp.

Allen, A. W., J. G. Cook, and M. J. Armbruster. 1984. Habitat suitability index models: Pronghorn. U.S. Fish and Wildlife Service, FWS/OBS-82/10.65. 22 pp.

Allen, A. W., P. A. Jordan, and J. W. Terrell. 1987. Habitat suitability index models: Moose, Lake Superior region. U.S. Fish and Wildlife Service Biological Report 82(10.155). 47 pp.

Armbruster, M. J. 1987. Habitat suitability index models: Greater sandhill crane. U.S. Fish and Wildlife Service Biological Report 82(10.140). 26 pp.

Bain, M. B., and J. L. Bain. 1982. Habitat suitability index models: Coastal stocks of striped bass. U.S. Fish and Wildlife Service, FWS/OBS-82/10.1. 29 pp.

Blumton, A. K., R. B. Owen, Jr., and W. B. Krohn. 1988. Habitat suitability index models: American eider (breeding). U.S. Fish and Wildlife Service Biological Report 82(10.149). 24 pp.

Boyle, K. A., and T. T. Fendley. 1987. Habitat suitability index models: Bobcat. U.S. Fish and Wildlife Service Biological Report 82(10.147). 16 pp.

Buckley, J. 1984. Habitat suitability index models: Larval and juvenile red drum. U.S. Fish and Wildlife Service, FWS/OBS-82/10.74. 15 pp.

Cade, B. S. 1985. Habitat suitability index models: American woodcock (wintering). U.S. Fish and Wildlife Service Biological Report 82(10.105). 23 pp.

Cade, B. S. 1986. Habitat suitability index models: Brown thrasher. U.S. Fish and Wildlife Service Biological Report 82(10.118). 14 pp.

Cade, B. S., and P. J. Sousa. 1985. Habitat suitability index models: Ruffed grouse. U.S. Fish and Wildlife Service Biological Report 82(10.86). 31 pp.

Cake, E. W., Jr. 1983. Habitat suitability index models: Gulf of Mexico American oyster. U.S. Fish and Wildlife Service, FWS/OBS-82/10.57. 37 pp.

Carreker, R. G. 1985. Habitat suitability index models: Least tern. U.S. Fish and Wildlife Service Biological Report 82(10.103). 29 pp.

Carreker, R. G. 1985. Habitat suitability index models: Snowshoe hare. U.S. Fish and Wildlife Service Biological Report 82(10.101). 21 pp.

Chapman, B. R., and R. J. Howard. 1984. Habitat suitability index models: Great egret. U.S. Fish and Wildlife Service, FWS/OBS-82/10.78. 23 pp.

Appendix A. Continued.

Christmas, J. Y., J. T. McBee, R. S. Waller, and F. C. Sutter, III. 1982. Habitat suitability index models: Gulf menhaden. U.S. Fish and Wildlife Service, FWS/OBS-82/10.23. 23 pp.

Clippinger, N. W. 1989. Habitat suitability index models: Black-tailed prairie dog. U.S. Fish and Wildlife Service Biological Report 82(10.156). 21 pp.

Cook, M. F., and R. C. Solomon. 1987. Habitat suitability index models: Muskellunge. U.S. Fish and Wildlife Service Biological Report 82(10.148). 33 pp.

Crance, J. H. 1984. Habitat suitability index models and instream flow suitability curves: Inland stocks of striped bass. U.S. Fish and Wildlife Service, FWS/OBS-82/10.85. 63 pp.

Crance, J. H. 1986. Habitat suitability index models and instream flow suitability curves: Shortnose sturgeon. U.S. Fish and Wildlife Service Biological Report 82(10.129). 31 pp.

Crance, J. H. 1987. Guidelines for using the Delphi technique to develop habitat suitability index curves. U.S. Fish and Wildlife Service Biological Report 82(10.134). 21 pp.

Diaz, R. J. 1982. Habitat suitability index models: Juvenile Atlantic croaker. U.S. Fish and Wildlife Service, FWS/OBS-82/10.21. 22 pp.

Diaz, R. J., and C. P. Onuf. 1985. Habitat suitability index models: Juvenile Atlantic croaker (revised). U.S. Fish and Wildlife Service Biological Report 82(10.98). 23 pp.

Edwards, E. A. 1983. Habitat suitability index models: Bigmouth buffalo. U.S. Fish and Wildlife Service, FWS/OBS-82/10.34. 23 pp.

Edwards, E. A. 1983. Habitat suitability index models: Longnose sucker. U.S. Fish and Wildlife Service, FWS/OBS-82/10.35. 21 pp.

Edwards, E. A., and K. A. Twomey. 1982. Habitat suitability index models: Common carp. U.S. Fish and Wildlife Service, FWS/OBS-82/10.12. 27 pp.

Edwards, E. A., and K. W. Twomey. 1982. Habitat suitability index models: Smallmouth buffalo. U.S. Fish and Wildlife Service, FWS/OBS-82/10.13. 28 pp.

Edwards, E. A., D. A. Krieger, G. Gebhart, and O. E. Maughan. 1982. Habitat suitability index models: White crappie. U.S. Fish and Wildlife Service, FWS/OBS-82/10.7. 22 pp.

Edwards, E. A., D. A. Krieger, M. Bacteller, and O. E. Maughan. 1982. Habitat suitability index models: Black crappie. U.S. Fish and Wildlife Service, FWS/OBS-82/10.6. 25 pp.

Edwards, E. A., G. Gebhart, and O. E. Maughan. 1983. Habitat suitability index information: Smallmouth bass. U.S. Fish and Wildlife Service, FWS/OBS-82/10.36. 47 pp.

Edwards, E. A., H. Li, and C. B. Schreck. 1983. Habitat suitability index models: Longnose dace. U.S. Fish and Wildlife Service, FWS/OBS-82/10.33. 13 pp.

Edwards, E. A., M. Bacteller, and O. E. Maughan. 1982. Habitat suitability index models: Slough darter. U.S. Fish and Wildlife Service, FWS/OBS-82/10.9. 13 pp.

Enge, K. M., and R. Mulholland. 1985. Habitat suitability index models: Southern and gulf flounders. U.S. Fish and Wildlife Service Biological Report 82(10.92). 25 pp.

Appendix A. Continued.

Faanes, C. A., and R. J. Howard. 1987. Habitat suitability index models: Black-shouldered kite. U.S. Fish and Wildlife Service Biological Report 82(10.130). 13 pp.

Finch, D. M., S. H. Anderson, and W. A. Hubert. 1987. Habitat suitability index models: Lark bunting. U.S. Fish and Wildlife Service Biological Report 82(10.137). 16 pp.

Graves, B. M., and S. H. Anderson. 1987. Habitat suitability index models: Bullfrog. U.S. Fish and Wildlife Service Biological Report 82(10.138). 22 pp.

Graves, B. M., and S. H. Anderson. 1987. Habitat suitability index models: Snapping turtle. U.S. Fish and Wildlife Service Biological Report 82(10.141). 18 pp.

Gutzwiller, K. J., and S. H. Anderson. 1987. Habitat suitability index models: Marsh wren. U.S. Fish and Wildlife Service Biological Report 82(10.139). 13 pp.

Hale, S. S., T. E. McMahon, and P. C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: Chum salmon. U.S. Fish and Wildlife Service Biological Report 82(10.108). 48 pp.

Hamilton, K., and P. C. Nelson. 1984. Habitat suitability index models and instream flow suitability curves: White bass. U.S. Fish and Wildlife Service Biological Report 82(10.89). 35 pp.

Hickman, T., and R. Raleigh. 1982. Habitat suitability index models: Cutthroat trout. U.S. Fish and Wildlife Service, FWS-OBS/82/10.5. 38 pp.

Hingtgen, T. M., R. Mulholland, and A. V. Zale. 1985. Habitat suitability index models: Eastern brown pelican. U.S. Fish and Wildlife Service Biological Report 82(10.90). 20 pp.

Hingtgen, T. M., R. Mulholland, and R. W. Repenning. 1985. Habitat suitability index models: White ibis. U.S. Fish and Wildlife Service Biological Report 82(10.93). 18 pp.

Howard, R. J., and H. A. Kantrud. 1983. Habitat suitability index models: Redhead (wintering). U.S. Fish and Wildlife Service, FWS/0BS-82/10.53. 14 pp.

Howard, R. J., and H. A. Kantrud. 1986. Habitat suitability index models: Northern pintail (gulf coast wintering). U.S. Fish and Wildlife Service Biological Report 82(10.121). 16 pp.

Hubert, W. A., R. S. Helzner, L. A. Lee, and P. C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: Arctic grayling riverine populations. U.S. Fish and Wildlife Service Biological Report 82(10.110). 34 pp.

Hubert, W. A., S. H. Anderson, P. D. Southall, and J. H. Crance. 1984. Habitat suitability index models and instream flow suitability curves: Paddlefish. U.S. Fish and Wildlife Service, FWS/OBS-82/10.80. 32 pp.

Inskip, P. D. 1982. Habitat suitability index models: Northern pike. U.S. Fish and Wildlife Service, FWS/OBS-82/10.17. 40 pp.

Jasikoff, T. M. 1982. Habitat suitability index models: Ferruginous hawk. U.S. Fish and Wildlife Service, FWS/OBS-82/10.10. 18 pp.

Jewett, S. C., and C. P. Onuf. 1988. Habitat suitability index models: Red king crab. U.S. Fish and Wildlife Service Biological Report 82 (10.153). 34 pp.

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Kaminski, R. M. 1986. Habitat suitability index models: Greater white-fronted goose (wintering). U.S. Fish and Wildlife Service Biological Report 82(10.116). 14 pp.

Kostecki, P. T. 1984. Habitat suitability index models: Spotted seatrout. U.S. Fish and Wildlife Service, FWS/OBS-82/10.75. 22 pp.

Krieger, D. A., J. W. Terrell, and P. C. Nelson. 1983. Habitat suitability information: Yellow perch. U.S. Fish and Wildlife Service, FWS/OBS-83/10.55. 37 pp.

Laymon, S. A., H. Salwasser, and R. H. Barrett. 1985. Habitat suitability index models: Spotted owl. U.S. Fish and Wildlife Service Biological Report 82(10.113). 114 pp.

Lee, L. A., and J. W. Terrell. 1987. Habitat suitability index models: Flathead catfish. U.S. Fish and Wildlife Service Biological Report 82(10.152). 39 pp.

Leslie, J. C., and P. J. Zwank. 1985. Habitat suitability index models: Lesser snow goose (wintering). U.S. Fish and Wildlife Service Biological Report 82(10.97). 16 pp.

Lewis, J. C. 1983. Habitat suitability index models: Roseate spoonbill. U.S. Fish and Wildlife Service, FWS/OBS-82/10.50. 16 pp.

Lewis, J. C., and R. L. Garrison. 1983. Habitat suitability index models: Clapper rail. U.S. Fish and Wildlife Service, FWS/OBS-82/10.51. 15 pp.

Lewis, J. C., and R. L. Garrison. 1984. Habitat suitability index models: American black duck (wintering). U.S. Fish and Wildlife Service, FWS/OBS-82/10.68. 16 pp.

Marcus, M. D., W. A. Hubert, and S. H. Anderson. 1984. Habitat suitability index models: Lake trout (exclusive of the Great Lakes). U.S. Fish and Wildlife Service, FWS/OBS-82/10.84. 12 pp.

Martin, R. P., and P. J. Zwank. 1987. Habitat suitability index models: Forster's tern (breeding)-Gulf and Atlantic coasts. U.S. Fish and Wildlife Service Biological Report 82(10.131). 21 pp.

McConnell, W. J., E. P. Bergersen, and K. L. Williamson. 1982. Habitat suitability index models: A low effort system for planned coolwater and coldwater reservoirs. U.S. Fish and Wildlife Service, FWS/OBS-82/10.3. 47 pp.

McConnell, W. J., E. P. Bergersen, and K. L. Williamson. 1984. Habitat suitability index models: A low effort system for planned coolwater and coldwater reservoirs (Revised). U.S. Fish and Wildlife Service, FWS/OBS-82/10.3A. 62 pp.

McKenzie, P. M., and P. J. Zwank. 1988. Habitat suitability index models: Black-bellied whistling duck (breeding). U.S. Fish and Wildlife Service Biological Report 82(10.150). 22 pp.

McMahon, T. E. 1982. Habitat suitability index models: Creek chub. U.S. Fish and Wildlife Service, FWS/OBS-82/10.4. 23 pp.

McMahon, T. E. 1983. Habitat suitability index models: Coho salmon. U.S. Fish and Wildlife Service, FWS/OBS-82/10.49. 29 pp.

McMahon, T. E., and J. W. Terrell. 1982. Habitat suitability index models: Channel catfish. U.S. Fish and Wildlife Service, FWS/OBS-82/10.2. 29 pp.

Appendix A. Continued.

McMahon, T. E., G. Gebhart, O. E. Maughan, and P. C. Nelson. 1984. Habitat suitability index models and instream flow suitability curves: Spotted bass. U.S. Fish and Wildlife Service, FWS/OBS-82/10.72. 41 pp.

McMahon, T. E., G. Gebhart, O. E. Maughan, and P. C. Nelson. 1984. Habitat suitability index models and instream flow suitability curves: Warmouth. U.S. Fish and Wildlife Service, FWS/OBS-82/10.67. 21 pp.

McMahon, T. E., J. W. Terrell, and P. C. Nelson. 1984. Habitat suitability information: Walleye. U.S. Fish and Wildlife Service, FWS/OBS-82/10.56. 43 pp.

Morreale, S. J., and J. W. Gibbons. 1986. Habitat suitability index models: Slider turtle. U.S. Fish and Wildlife Service Biological Report 82(10.125). 14 pp.

Mulholland, R. 1984. Habitat suitability index models: Hard clam. U.S. Fish and Wildlife Service, FWS/OBS-82/10.77. 21 pp.

Mulholland, R. 1984. Habitat suitability index models: Pink shrimp. U.S. Fish and Wildlife Service, FWS/OBS-82/10.76. 17 pp.

Mulholland, R. 1985. Habitat suitability index models: Lesser scaup (wintering). U.S. Fish and Wildlife Service Biological Report 82(10.91). 15 pp.

Newsom, J. D., T. Joanen, and R. J. Howard. 1987. Habitat suitability index models: American alligator. U.S. Fish and Wildlife Service Biological Report 82(10.136). 14 pp.

Palmer, W. M., and C. L. Cordes. 1988. Habitat suitability index models: Diamondback terrapin (nesting)-Atlantic coast. U.S. Fish and Wildlife Service Biological Report 82(10.151). 18 pp.

Pardue, G. B. 1983. Habitat suitability index models: Alewife and blueback herring. U.S. Fish and Wildlife Service, FWS/OBS-82/10.58. 22 pp.

Peterson, A. 1986. Habitat suitability index models: Bald eagle (breeding season). U.S. Fish and Wildlife Service Biological Report 82(10.126). 25 pp.

Prose, B. L. 1985. Habitat suitability index models: Belted kingfisher. U.S. Fish and Wildlife Service Biological Report 82(10.87). 22 pp.

Prose, B. L. 1985. Habitat suitability index models: Greater prairie-chicken (multiple levels of resolution). U.S. Fish and Wildlife Service Biological Report 82(10.102). 33 pp.

Prose, B. L. 1987. Habitat suitability index models: Plains sharp-tailed grouse. U.S. Fish and Wildlife Service Biological Report 82(10.142). 31 pp.

Raleigh, R. F. 1982. Habitat suitability index models: Brook trout. U.S. Fish and Wildlife Service, FWS/OBS-82/10.24. 42 pp.

Raleigh, R. F., and P. C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: Pink salmon. U.S. Fish and Wildlife Service Biological Report 82(10.109). 36 pp.

Raleigh, R. F., L. D. Zuckerman, and P. C. Nelson. 1984. Habitat suitability index models and instream flow suitability curves: Brown trout. U.S. Fish and Wildlife Service, FWS/OBS-82/10.71. 71 pp.

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Raleigh, R. F., L. D. Zuckerman, and P. C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: Brown trout, revised. U.S. Fish and Wildlife Service Biological Report 82(10.124). 65 pp.

Raleigh, R. F., T. Hickman, R. C. Solomon, and P. C. Nelson. 1984. Habitat suitability information: Rainbow trout. U.S. Fish and Wildlife Service, FWS/OBS-82/10.60. 64 pp.

Raleigh, R. F., W. J. Miller, and P. C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: Chinook salmon. U.S. Fish and Wildlife Service Biological Report 82(10.122). 64 pp.

Rodnick, K., and H. W. Li. 1983. Habitat suitability index models: Littleneck clam. U.S. Fish and Wildlife Service, FWS/OBS-82/10.59. 15 pp.

Rogers, L. L., and A. W. Allen. 1987. Habitat suitability index models: Black bear, Upper Great Lakes Region. U.S. Fish and Wildlife Service Biological Report 82(10.144). 54 pp.

Rorabaugh, J. C., and P. J. Zwank. 1983. Habitat suitability index models: Mottled duck. U.S. Fish and Wildlife Service, FWS/OBS-82/10.52. 26 pp.

Schamberger, M., A. H. Farmer, and J. W. Terrell. 1982. Habitat suitability index models: Introduction. U.S. Fish and Wildlife Service, FWS/OBS-82/10. 2 pp.

Schroeder, R. L. 1982. Habitat suitability index models: Black-capped chickadee. U.S. Fish and Wildlife Service, FWS/OBS-82/10.37. 12 pp.

Schroeder, R. L. 1982. Habitat suitability index models: Downy woodpecker. U.S. Fish and Wildlife Service, FWS/OBS-82/10.38. 10 pp.

Schroeder, R. L. 1982. Habitat suitability index models: Pileated woodpecker. U.S. Fish and Wildlife Service, FWS/OBS-82/10.39. 15 pp.

Schroeder, R. L. 1982. Habitat suitability index models: Pine warbler. U.S. Fish and Wildlife Service, FWS/OBS-82/10.28. 8 pp.

Schroeder, R. L. 1982. Habitat suitability index models: Yellow warbler. U.S. Fish and Wildlife Service, FWS/OBS-82/10.27. 7 pp.

Schroeder, R. L. 1982. Habitat suitability index models: Yellow-headed blackbird. U.S. Fish and Wildlife Service, FWS/OBS-82/10.26. 12 pp.

Schroeder, R. L. 1984. Habitat suitability index models: Black brant. U.S. Fish and Wildlife Service, FWS/OBS-82/10.63. 11 pp.

Schroeder, R. L. 1984. Habitat suitability index models: Blue grouse. U.S. Fish and Wildlife Service, FWS/OBS-82/10.81. 19 pp.

Schroeder, R. L. 1984. Habitat suitability index models: Canvasback (breeding habitat). U.S. Fish and Wildlife Service, FWS/OBS-82/10.82. 16 pp.

Schroeder, R. L. 1985. Habitat suitability index models: Eastern wild turkey. U.S. Fish and Wildlife Service Biological Report 82(10.106). 33 pp.

Schroeder, R. L. 1985. Habitat suitability index models: Northern bobwhite. U.S. Fish and Wildlife Service Biological Report 82(10.104). 32 pp.

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Schroeder, R. L. 1985. Habitat suitability index models: Pine warbler. U.S. Fish and Wildlife Service, FWS/OBS-82/10.28 Revised. 8 pp.

Schroeder, R. L. 1986. Habitat suitability index models: Wildlife species richness in shelterbelts. U.S. Fish and Wildlife Service Biological Report 82(10.128). 17 pp.

Schroeder, R. L., and P. J. Sousa. 1982. Habitat suitability index models: Eastern meadowlark. U.S. Fish and Wildlife Service, FWS/OBS-82/10.29. 9 pp.

Short, H. L. 1984. Habitat suitability index models: Brewer's sparrow. U.S. Fish and Wildlife Service, FWS/OBS-82/10.83. 16 pp.

Short, H. L. 1984. Habitat suitability index models: The Arizona guild and layers of habitat models. U.S. Fish and Wildlife Service, FWS/OBS-82/10.70. 37 pp.

Short, H. L. 1984. Habitat suitability index models: Western grebe. U.S. Fish and Wildlife Service, FWS/OBS-82/10.69. 20 pp.

Short, H. L. 1985. Habitat suitability index models: Cactus wren. U.S. Fish and Wildlife Service Biological Report 82(10.96). 15 pp.

Short, H. L. 1985. Habitat suitability index models: Red-winged blackbird. U.S. Fish and Wildlife Service Biological Report 82(10.95). 20 pp.

Short, H. L. 1986. Habitat suitability index models: White-tailed deer in the Gulf of Mexico and South Atlantic coastal plains. U.S. Fish and Wildlife Service Biological Report 82(10.123). 36 pp.

Short, H. L., and R. J. Cooper. 1985. Habitat suitability index models: Great blue heron. U.S. Fish and Wildlife Service Biological Report 82(10.99). 23 pp.

Sikora, W. B., and J. P. Sikora. 1982. Habitat suitability index models: Southern kingfish. U.S. Fish and Wildlife Service, FWS/OBS-82/10.31. 22 pp.

Sousa, P. J. 1982. Habitat suitability index models: Lewis' woodpecker. U.S. Fish and Wildlife Service, FWS/OBS-82/10.32. 14 pp.

Sousa, P. J. 1982. Habitat suitability index models: Veery. U.S. Fish and Wildlife Service, FWS/OBS-82/10.22. 12 pp.

Sousa, P. J. 1983. Habitat suitability index models: Field sparrow. U.S. Fish and Wildlife Service, FWS/OBS-82/10.62. 14 pp.

Sousa, P. J. 1983. Habitat suitability index models: Williamson's sapsucker. U.S. Fish and Wildlife Service, FWS/OBS-82/10.47. 13 pp.

Sousa, P. J. 1985. Habitat suitability index models: Blue-winged teal (breeding). U.S. Fish and Wildlife Service Biological Report 82(10.114). 36 pp.

Sousa, P. J. 1985. Habitat suitability index models: Gadwall (breeding). U.S. Fish and Wildlife Service Biological Report 82(10.100). 35 pp.

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Sousa, P. J., and A. H. Farmer. 1983. Habitat suitability index models: Wood duck. U.S. Fish and Wildlife Service, FWS/OBS-82/10.43. 27 pp.

Sousa, P. J., and W. N. McDonal. 1983. Habitat suitability index models: Baird's sparrow. U.S. Fish and Wildlife Service, FWS/OBS-82/10.44. 12 pp.

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Appendix B. Species life stages, species, species groups, and communities in the HSI model series.

Taxon or group	Publication number
Communities	
Layers of habitat	10.70
Wildlife guilds	10.70
Wildlife species richness	10.128
Mammals	
Beaver	10.30, 10.30 Revised
Black bear	10.144
Black-tailed prairie dog	10.156
Bobcat	10.147
Eastern cottontail	10.66
Fisher	10.45
Fox squirrel	10.18
Gray squirrel	10.19, 10.135
Marten	10.11
Mink	10.61, 10.127
Moose	10.155
Muskrat	10.46
Pronghorn	10.65
Snowshoe hare	10.101
Southern red-backed vole (western United States)	10.42
Swamp rabbit	10.107
White-tailed deer (coastal plain)	10.123
Birds	
American black duck (wintering)	10.68
American coot	10.115
American eider (breeding)	10.149
American woodcock (wintering)	10.105
Baird's sparrow	10.44
Bald eagle (breeding season)	10.126
Barred owl	10.143
Belted kingfisher	10.87
Black brant (Brant ssp. *nigricans*)	10.63
Black-bellied whistling-duck	10.150
Black-capped chickadee	10.37
Black-shouldered kite (White-tailed kite)	10.130
Blue grouse	10.81
Blue-winged teal (breeding)	10.114
Brewer's sparrow	10.83

Appendix B. Continued.

Taxon or group	Publication number
Brown thrasher	10.118
Cactus wren	10.96
Canvasback (breeding)	10.82
Clapper rail	10.51
Downy woodpecker	10.38
Eastern brown pelican	10.90
Eastern meadowlark	10.29
Eastern wild turkey	10.106
Ferruginous hawk	10.10
Field sparrow	10.62
Forster's tern (breeding)	10.131
Gadwall (breeding)	10.100
Gray partridge	10.73
Great blue heron	10.99
Great egret	10.78
Greater prairie-chicken	10.102
Greater sandhill crane	10.140
Greater white-fronted goose (wintering)	10.116
Hairy woodpecker	10.146
Lark bunting	10.137
Laughing gull	10.94
Least tern	10.103
Lesser scaup (breeding)	10.117
Lesser scaup (wintering)	10.91
Lesser snow goose (wintering)	10.97
Lewis' woodpecker	10.32
Mallard (winter habitat)	10.132
Marsh wren	10.139
Mottled duck	10.52
Northern bobwhite	10.104
Northern pintail	10.145
Northern pintail (gulf coast)	10.121
Osprey	10.154
Pileated woodpecker	10.39
Pine warbler	10.28, 10.28 Revised
Plains sharp-tailed grouse	10.142
Redhead (wintering)	10.53
Red-winged blackbird	10.95
Roseate spoonbill	10.50
Ruffed grouse	10.86
Shelterbelt community	10.128
Spotted owl	10.113
Veery	10.22
Western grebe	10.69
White ibis	10.93
Williamson's sapsucker	10.47

Appendix B. Continued.

Taxon or group	Publication number
Wood duck	10.43
Yellow warbler	10.27
Yellow-headed blackbird	10.26
Reptiles	
American alligator	10.136
Diamondback terrapin (nesting)	10.151
Slider turtle (common slider)	10.125
Snapping turtle	10.141
Amphibians	
Bullfrog	10.138
Red-spotted newt	10.111
Fish	
Alewife	10.58
American shad	10.88
Arctic grayling	10.110
Atlantic croaker (juvenile)	10.21, 10.98
Bigmouth buffalo	10.34
Black bullhead	10.14
Black crappie	10.3, 10.3A, 10.6
Blacknose dace	10.41
Blueback herring	10.58
Bluegill	10.08
Brook trout	10.24, 10.25
Brown trout	10.71, 10.124, 10.25
Channel catfish	10.2
Chinook salmon	10.122
Chum salmon	10.108
Coho salmon	10.25, 10.49
Common carp	10.3, 10.3A, 10.12
Common shiner	10.40
Creek chub	10.4
Cutthroat trout	10.5, 10.25
English sole (juvenile)	10.133
Esox spp.	10.25
Fallfish	10.48
Flathead catfish	10.152
Flounder (southern and gulf coast)	10.92
Gizzard shad	10.112

Appendix B. Concluded.

Taxon or group	Publication number
Green sunfish	10.15
Gulf menhaden	10.23
Inland silverside	10.120
Kokanee salmon	10.25
Lake trout	10.25, 10.84
Largemouth bass	10.16
Longnose dace	10.33
Longnose sucker	10.35
Muskellunge	10.25, 10.148
Northern pike	10.17, 10.25
Paddlefish	10.80
Pink salmon	10.109
Rainbow trout	10.25, 10.60
Rainbow trout (put-and-grow)	10.3, 10.3A
Red drum (larval and juvenile)	10.74
Redbreast sunfish	10.119
Redear sunfish	10.79
Sauger	10.25
Shortnose sturgeon	10.129
Slough darter	10.9
Smallmouth bass	10.36
Smallmouth buffalo	10.13
Southern kingfish	10.31
Spotted bass	10.72
Spotted seatrout	10.75
Spot (juvenile)	10.20
Striped bass (coastal)	10.1
Striped bass (inland)	10.85
Walleye	10.25, 10.56
Warmouth	10.67
White bass	10.89
White crappie	10.7
White sucker	10.3, 10.3A, 10.64
Yellow perch	10.3, 10.3A, 10.25, 10.55
Invertebrates	
American oyster (Gulf of Mexico stocks) [Eastern American oyster]	10.57
Brown shrimp	10.54
Hard clam	10.77
Littleneck clam	10.59
Pink shrimp	10.76
Red king crab	10.153
White shrimp	10.54

Appendix C. HSI model series, numerical order, with authors.

Publication number	Authors
10	Schamberger et al. (1982)
10.A	Terrell et al. (1982)
10.1	Bain and Bain (1982)
10.2	McMahon and Terrell (1982)
10.3	McConnell et al. (1982)
10.3A	McConnell et al. (1984)
10.4	McMahon (1982)
10.5	Hickman and Raleigh (1982)
10.6	Edwards et al. (1982)
10.7	Edwards et al. (1982)
10.8	Stuber et al. (1982)
10.9	Edwards et al. (1982)
10.10	Jasikoff (1982)
10.11	Allen (1982)
10.12	Edwards and Twomey (1982)
10.13	Edwards and Twomey (1982)
10.14	Stuber (1982)
10.15	Stuber et al. (1982)
10.16	Stuber et al. (1982)
10.17	Inskip (1982)
10.18	Allen (1982)
10.19	Allen (1982)
10.20	Stickney and Cuenco (1982)
10.21	Diaz (1982)
10.22	Sousa (1982)
10.23	Christmas et al. (1982)
10.24	Raleigh (1982)
10.25	Aggus and Bivin (1982)
10.26	Schroeder (1982)
10.27	Schroeder (1982)
10.28	Schroeder (1982)
10.28 (Revised)	Schroeder (1985)
10.29	Schroeder and Sousa (1982)
10.30	Allen (1982)
10.30 (Revised)	Allen (1983)
10.31	Sikora and Sikora (1982)
10.32	Sousa (1982)
10.33	Edwards et al. (1983)
10.34	Edwards (1983)
10.35	Edwards (1983)
10.36	Edwards et al. (1983)
10.37	Schroeder (1982)
10.38	Schroeder (1982)
10.39	Schroeder (1982)
10.40	Trial et al. (1983)
10.41	Trial et al. (1983)
10.42	Allen (1983)

Appendix C. Continued.

Publication number	Authors
10.43	Sousa and Farmer (1983)
10.44	Sousa and McDonal (1983)
10.45	Allen (1983)
10.46	Allen and Hoffman (1984)
10.47	Sousa (1983)
10.48	Trial et al. (1983)
10.49	McMahon (1983)
10.50	Lewis (1983)
10.51	Lewis and Garrison (1983)
10.52	Rorabaugh and Zwank (1983)
10.53	Howard and Kantrud (1983)
10.54	Turner and Brody (1983)
10.55	Krieger et al. (1983)
10.56	McMahon et al. (1984)
10.57	Cake (1983)
10.58	Pardue (1983)
10.59	Rodnick and Li (1983)
10.60	Raleigh et al. (1984)
10.61	Allen (1983)
10.62	Sousa (1983)
10.63	Schroeder (1984)
10.64	Twomey et al. (1984)
10.65	Allen et al. (1984)
10.66	Allen (1984)
10.67	McMahon et al. (1984)
10.68	Lewis and Garrison (1984)
10.69	Short (1984)
10.70	Short (1984)
10.71	Raleigh et al. (1984)
10.72	McMahon et al. (1984)
10.73	Allen (1984)
10.74	Buckley (1984)
10.75	Kostecki (1984)
10.76	Mulholland (1984)
10.77	Mulholland (1984)
10.78	Chapman and Howard (1984)
10.79	Twomey et al. (1984)
10.80	Hubert et al. (1984)
10.81	Schroeder (1984)
10.82	Schroeder (1984)
10.83	Short (1984)
10.84	Marcus et al. (1984)
10.85	Crance (1984)
10.86	Cade and Sousa (1985)
10.87	Prose (1985)
10.88	Stier and Crance (1985)
10.89	Hamilton and Nelson (1984)

Appendix C. Continued.

Publication number	Authors
10.90	Hingtgen et al. (1985)
10.91	Mulholland (1985)
10.92	Enge and Mulholland (1985)
10.93	Hingtgen et al. (1985)
10.94	Zale and Mulholland (1985)
10.95	Short (1985)
10.96	Short (1985)
10.97	Leslie and Zwank (1985)
10.98	Diaz and Onuf (1985)
10.99	Short and Cooper (1985)
10.100	Sousa (1985)
10.101	Carreker (1985)
10.102	Prose (1985)
10.103	Carreker (1985)
10.104	Schroeder (1985)
10.105	Cade (1985)
10.106	Schroeder (1985)
10.107	Allen (1985)
10.108	Hale et al. (1985)
10.109	Raleigh and Nelson (1985)
10.110	Hubert et al. (1985)
10.111	Sousa (1985)
10.112	Williamson and Nelson (1985)
10.113	Laymon et al. (1985)
10.114	Sousa (1985)
10.115	Allen (1985)
10.116	Kaminski (1986)
10.117	Allen (1986)
10.118	Cade (1986)
10.119	Aho et al. (1986)
10.120	Weinstein (1986)
10.121	Howard and Kantrud (1986)
10.122	Raleigh et al. (1986)
10.123	Short (1986)

Appendix C. Concluded.

Publication number	Authors
10.124	Raleigh et al. (1986)
10.125	Morreale and Gibbons (1986)
10.126	Peterson (1986)
10.127	Allen (1986)
10.128	Schroeder (1986)
10.129	Crance (1986)
10.130	Faanes and Howard (1987)
10.131	Martin and Zwank (1987)
10.132	Allen (1986)
10.133	Toole et al. (1987)
10.134	Crance (1987)
10.135	Allen (1987)
10.136	Newsom et al. (1987)
10.137	Finch et al. (1987)
10.138	Graves and Anderson (1987)
10.139	Gutzwiller and Anderson (1987)
10.140	Armbruster (1987)
10.141	Graves and Anderson (1987)
10.142	Prose (1987)
10.143	Allen (1987)
10.144	Rogers and Allen (1987)
10.145	Suchy and Anderson (1987)
10.146	Sousa (1987)
10.147	Boyle and Fendley (1987)
10.148	Cook and Solomon (1987)
10.149	Blumton et al. (1988)
10.150	McKenzie and Zwank (1988)
10.151	Palmer and Cordes (1988)
10.152	Lee and Terrell (1987)
10.153	Jewett and Onuf (1988)
10.154	Vana-Miller (1987)
10.155	Allen et al. (1987)
10.156	Clippinger (1989)

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13. ABSTRACT (Maximum 200 words)

The U.S. Department of the Interior conducted or provided support for numerous Habitat Suitability Index (HSI) model evaluations between January 1, 1982, and October 1, 1995. Results of this program are dispersed among various journals, theses, dissertations, and unpublished reports. In order to simplify use of this scattered information, this publication provides referenced summaries of unpublished HSI model evaluations that were initiated by the U.S. Fish and Wildlife Service. For a limited number of species, published HSI model evaluations are summarized.

All of the authors of the individual synopses were involved in the development and testing of HSI models. Except for Janelle Corn (who is in the final stages of completing a Ph.D. program at Colorado State University), all of the authors currently work for the Biological Resources Division of the U.S. Geological Survey.

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